INCREMENTAL VOLUME VISUALISATION

for large streaming datasets

Derek Gerstmann
email: derek.gerstmann [at] uwa.edu.au
web: http://local.wasp.uwa.edu.au/~derek/cmca/

Centre for Microscopy, Characterisation and Analysis (CMCA)
Western Australian Supercomputing Program (WASP)
University of Western Australia (UWA)

PRESENTATION OUTLINE

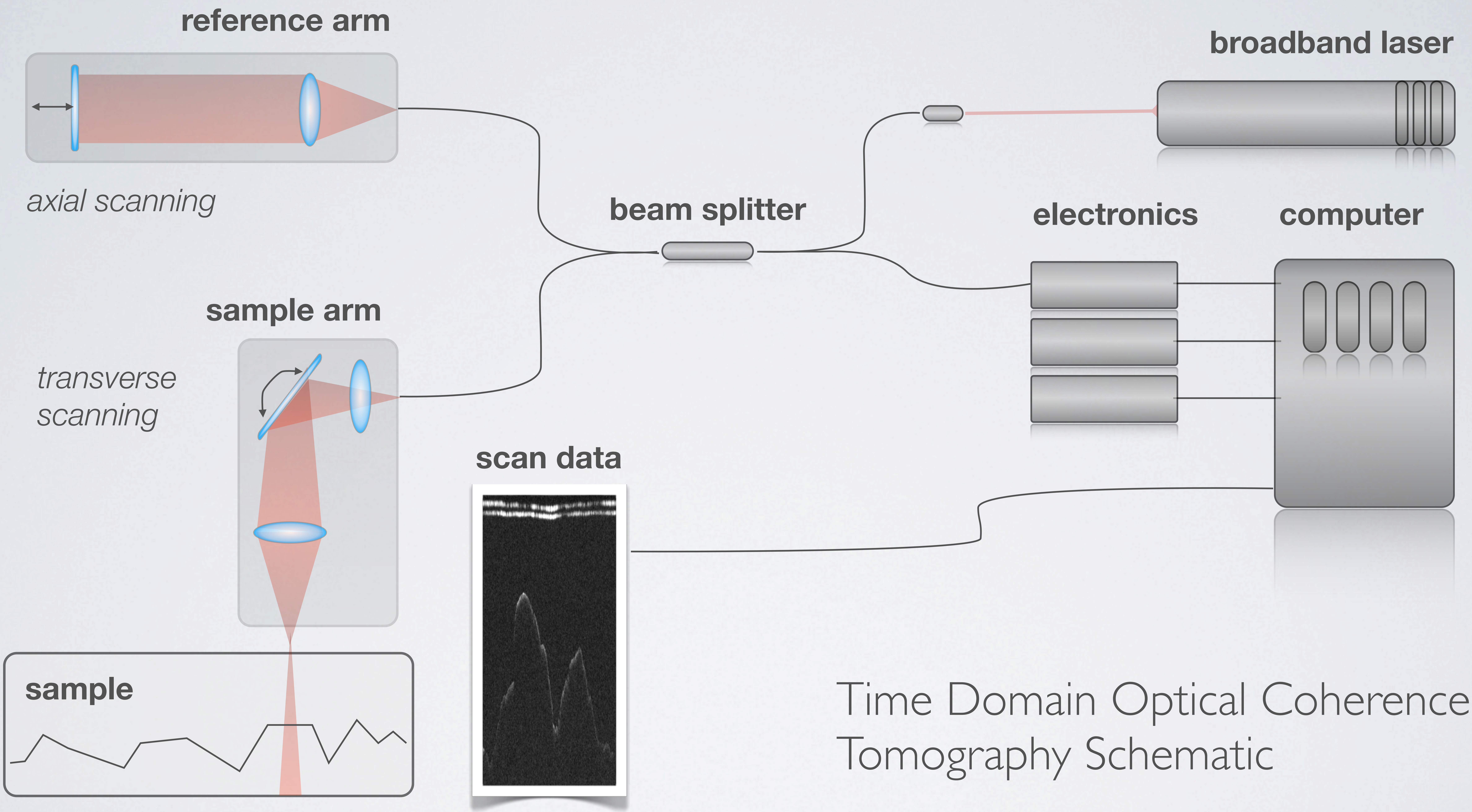
- **OVERVIEW**
  - Motivation
  - Requirements
  - Technique
  - Implementation
  - Results

MOTIVATION

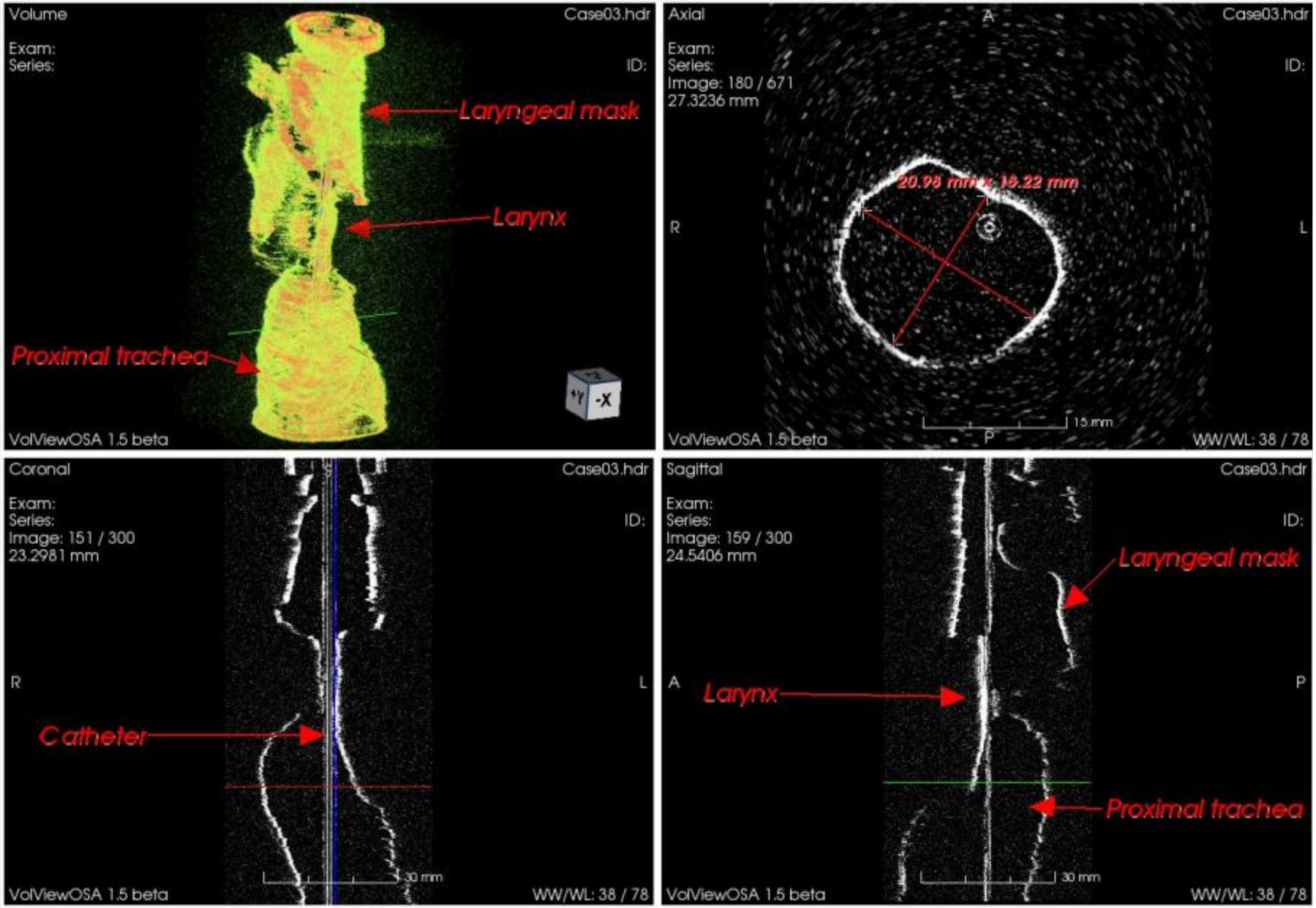
- **LARGE STREAMING DATASETS**
  - Process data online / handle live-scans / in-situ visualisation
  - Incremental reconstruction done on the fly
  - Produce an interactive rendering

MOTIVATION

- **SPECIFIC USE-CASE**
  - Process a live-scan from a novel optical coherence tomography (OCT) probe
    - Endoscopic anatomical OCT probe with a 3d magnetic tracker for imaging airways
  - Process high-resolution line-scans and produce accurate volume reconstruction



Time Domain Optical Coherence Tomography Schematic


Volume
Case03.hdr
Exam:
Series:
ID:
Laryngeal mask
Larynx
Proximal trachea
VolViewOSA 1.5 beta
Axial
Case03.hdr
Exam:
Series:
Image: 180 / 671
27.3236 mm
ID:
A
R
L
P
20.98 mm x 18.22 mm
15 mm
VolViewOSA 1.5 beta
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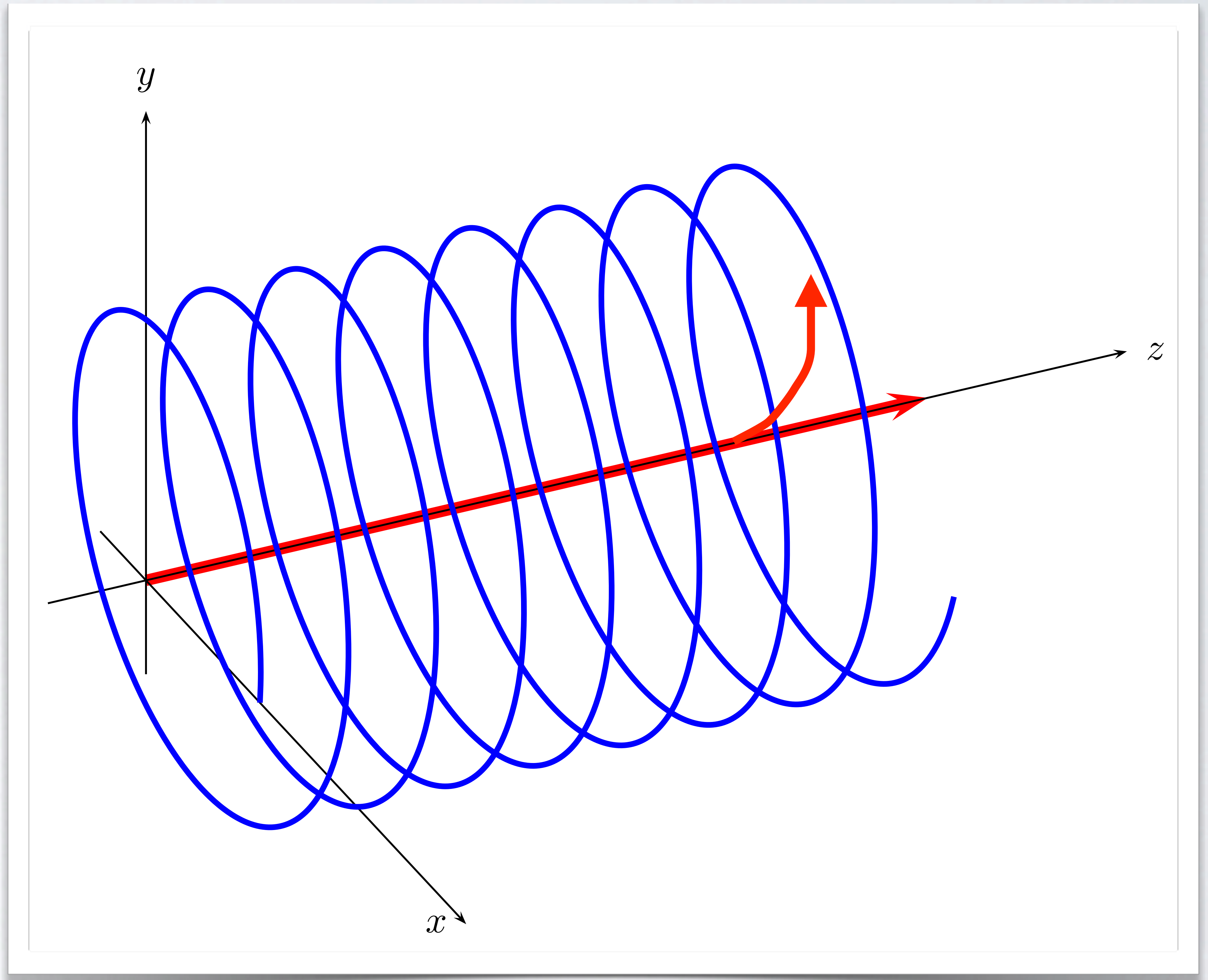
24.5406 mm
ID:
Laryngeal mask
A
P
Larynx
Proximal trachea
30 mm
VolViewOSA 1.5 beta
WW/WL: 38 / 78

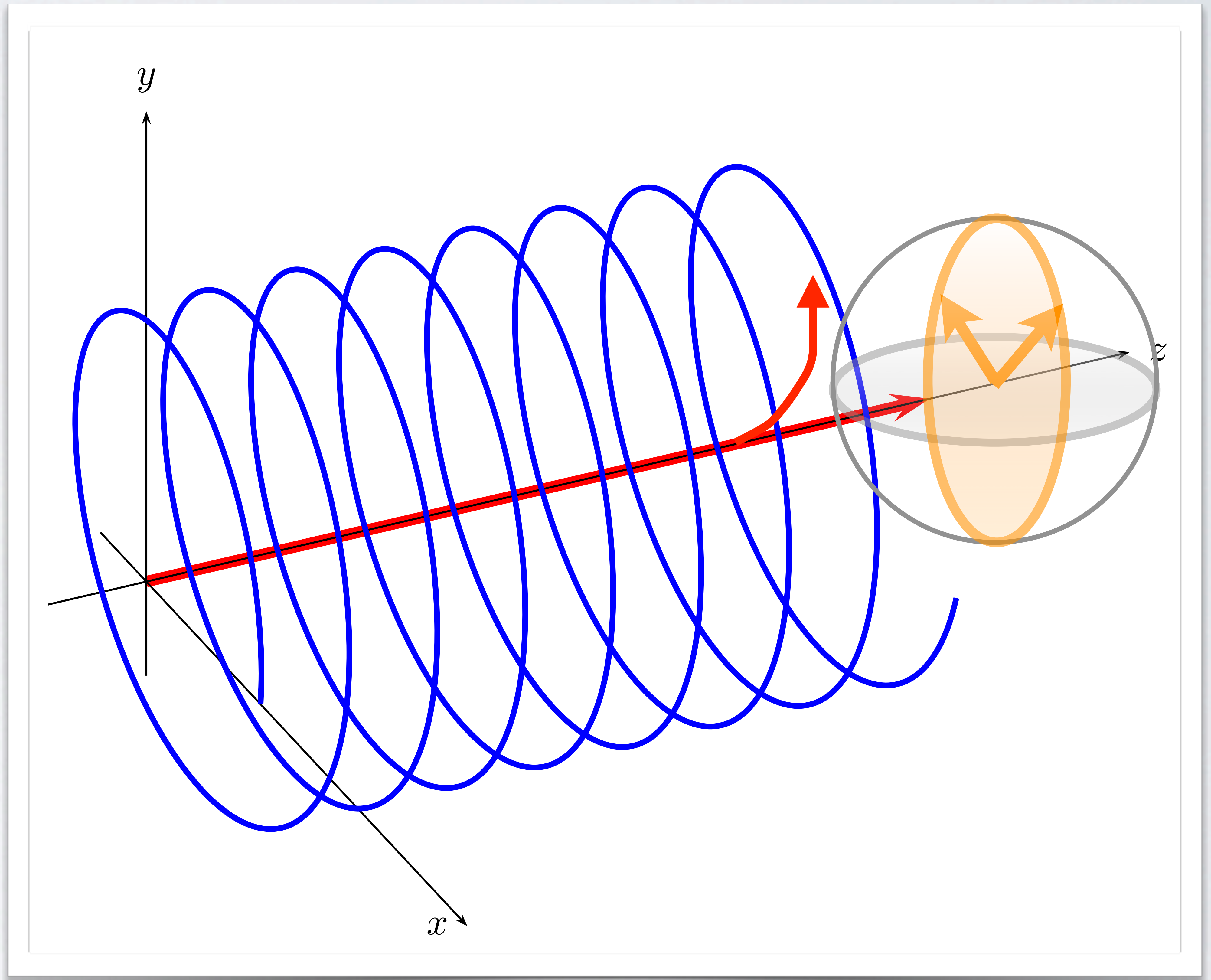
ENDOSCOPIC ANATOMICAL OCT

- **ACQUISITION**
  - Scanner produces line scans while moving forward and rotating about an axis in a spiral arc
  - Probe rotates at 1.25Hz, moves at 1.35mm/sec, scans at 900Hz along optical path.



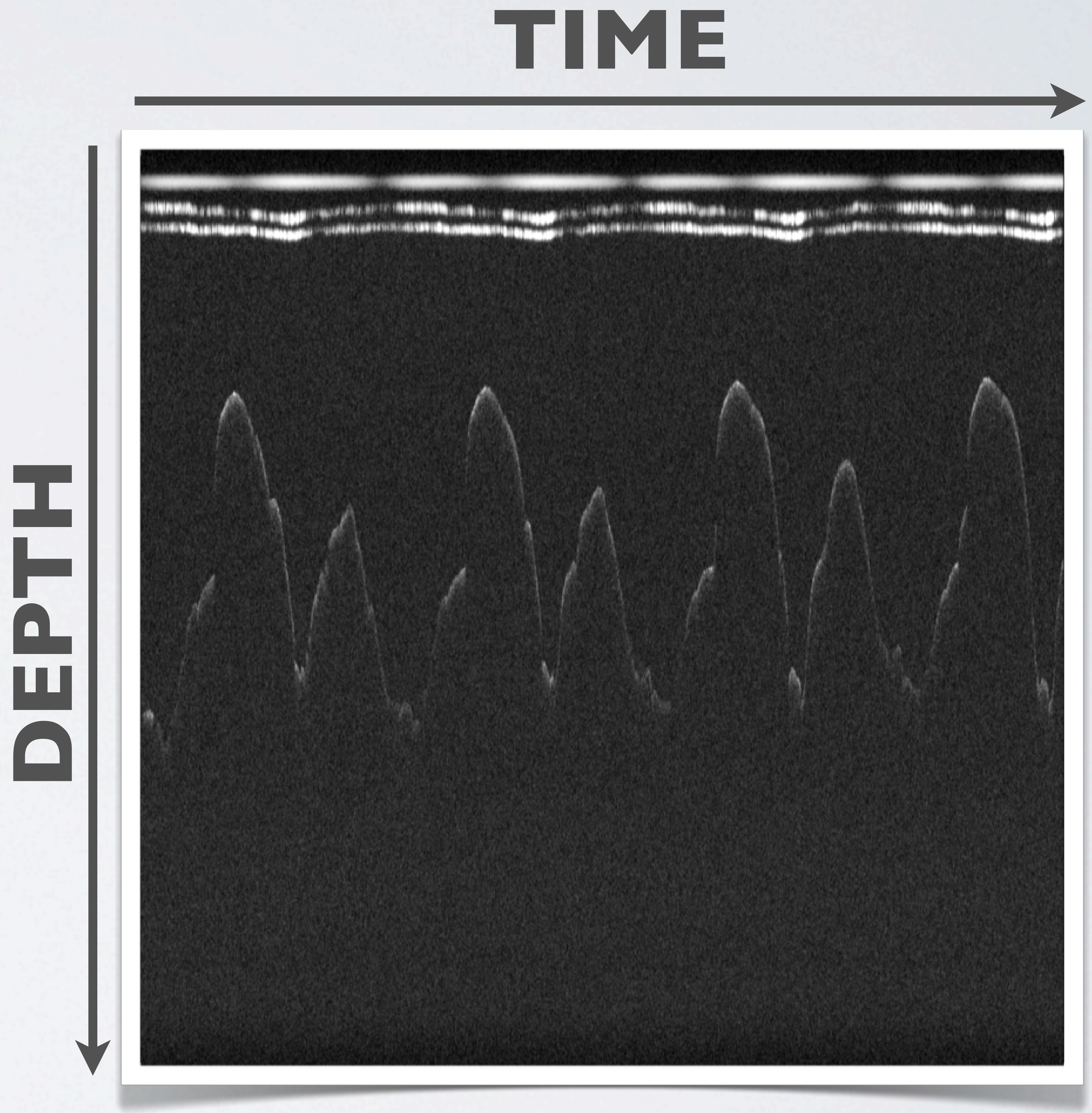
ENDOSCOPIC ANATOMICAL OCT

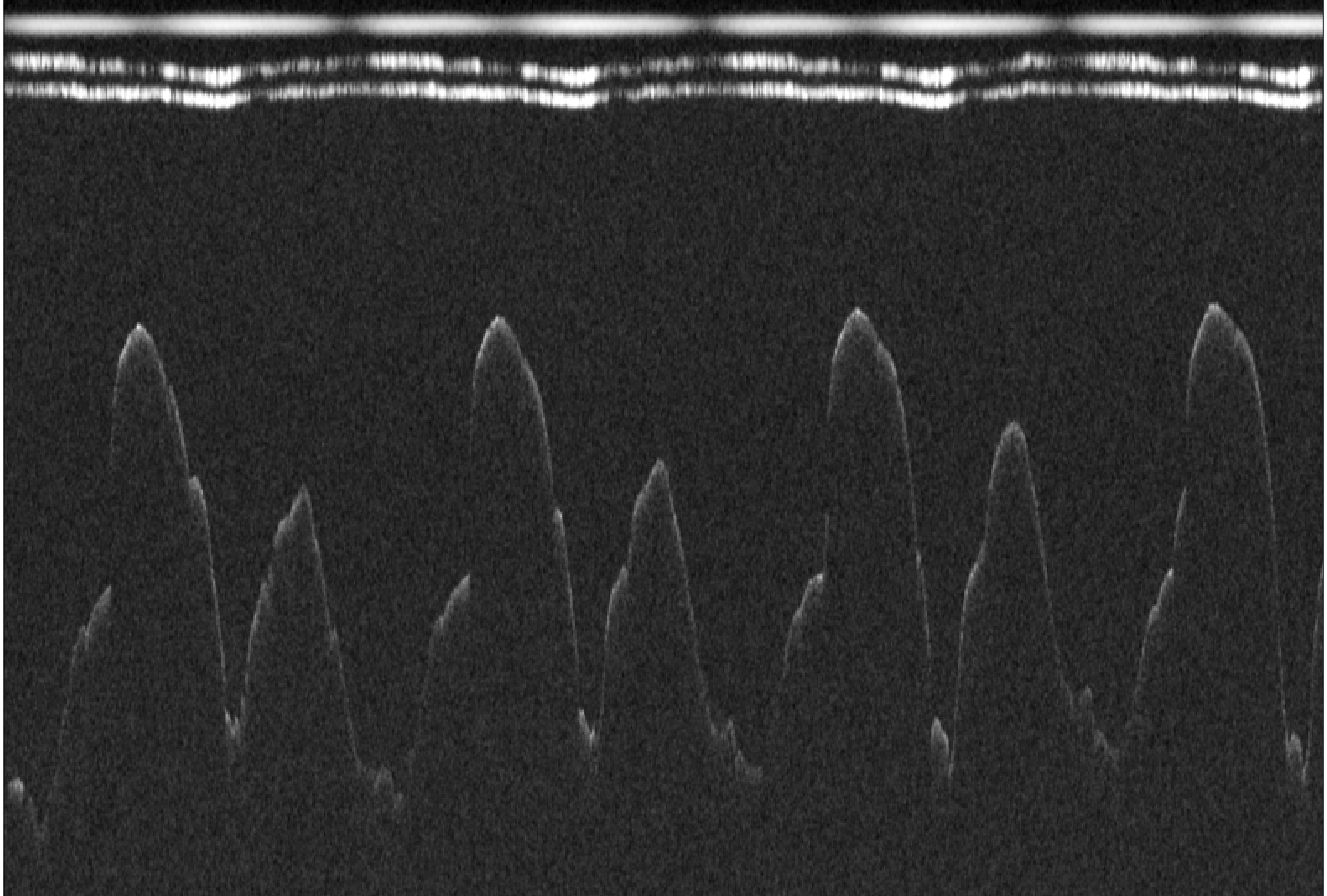
- **ACQUISITION**
  - Magnetic tracker records position and orientation of scanning probe
  - Records spatial orientation at 240 Hz

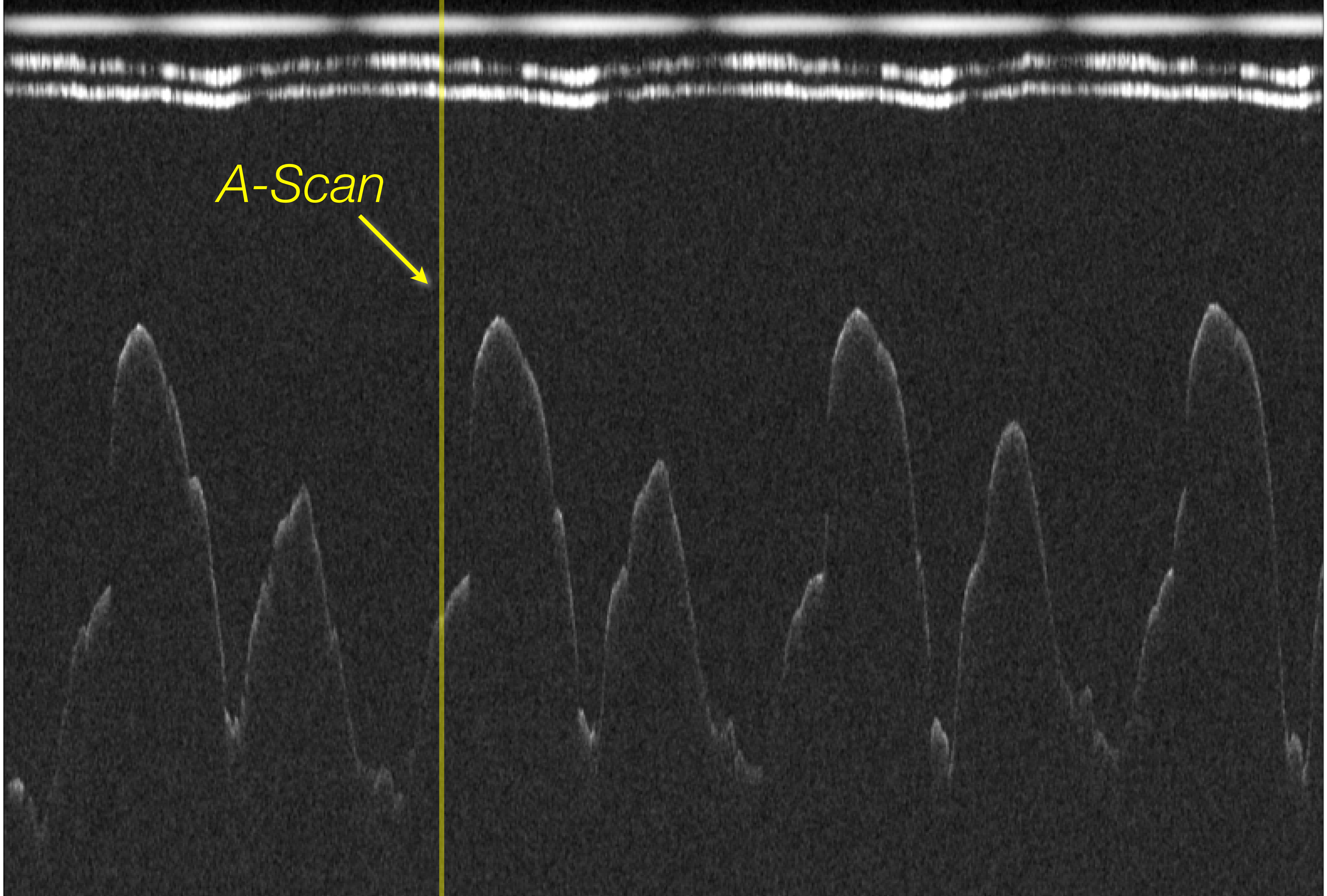


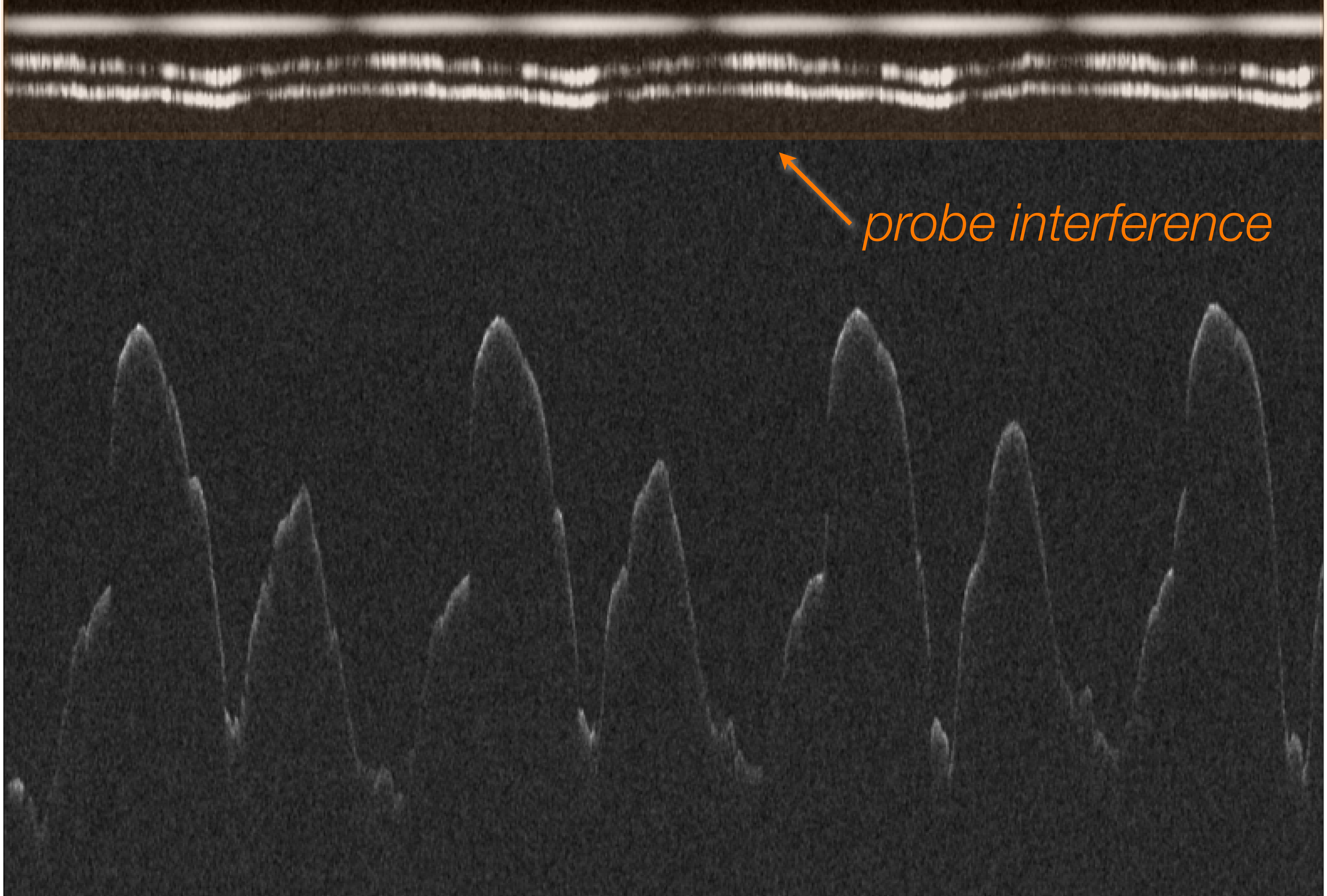
ENDOSCOPIC ANATOMICAL OCT

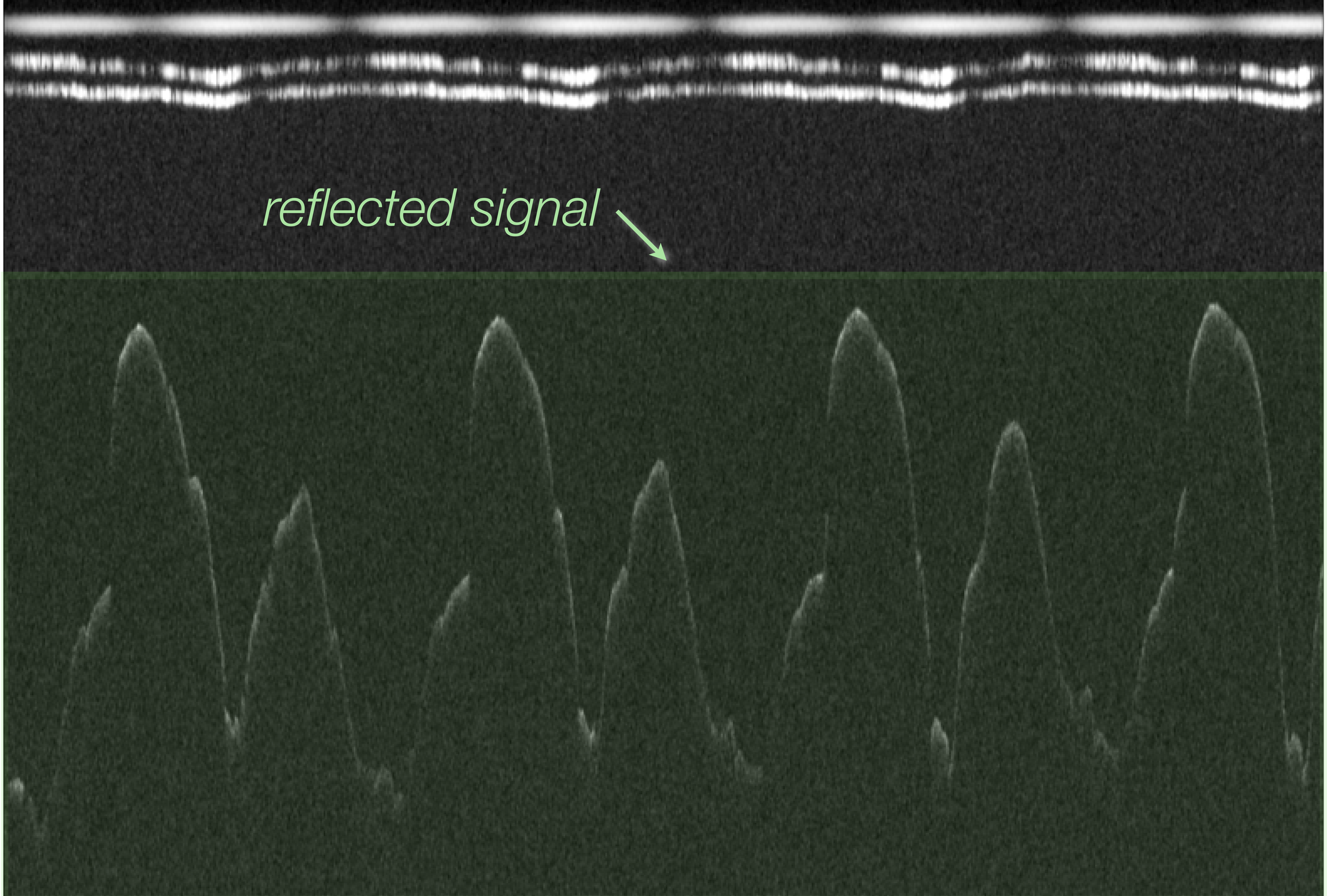
- **ACQUISITION**
  - Each line scan contains 2048 pixels which record intensity values from reflected light at increasing depths
  - Tracker records position and orientation of scanning probe (at 240 Hz)

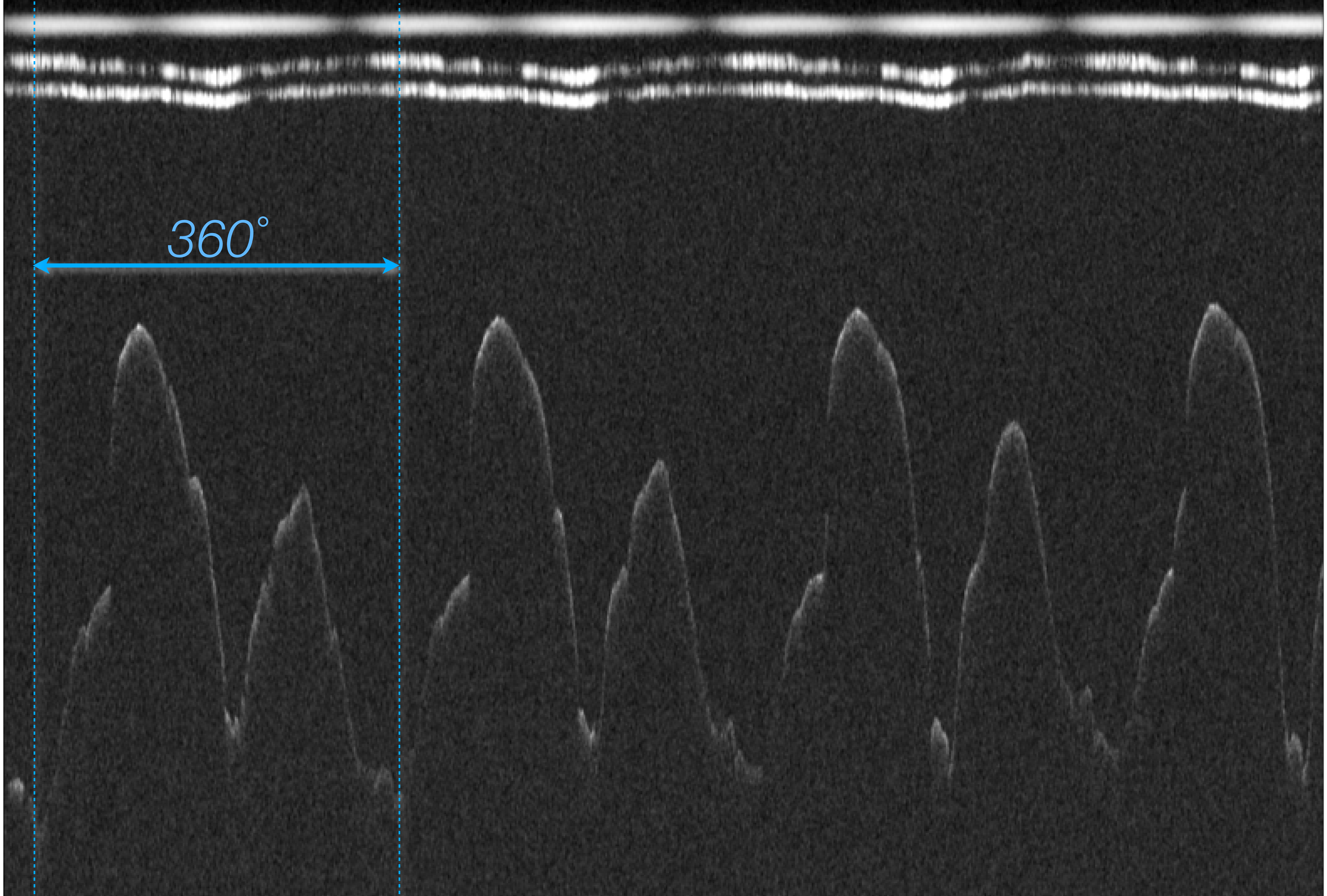





A-Scan


probe interference


reflected signal


360°

REQUIREMENTS

- **SYSTEM REQUIREMENTS**
  - Scanner outputs multiple data files stored on disk in proprietary format
  - System designed for use in a clinical theatre which has limited space
  - Need a proper volumetric representation that matches the object being scanned

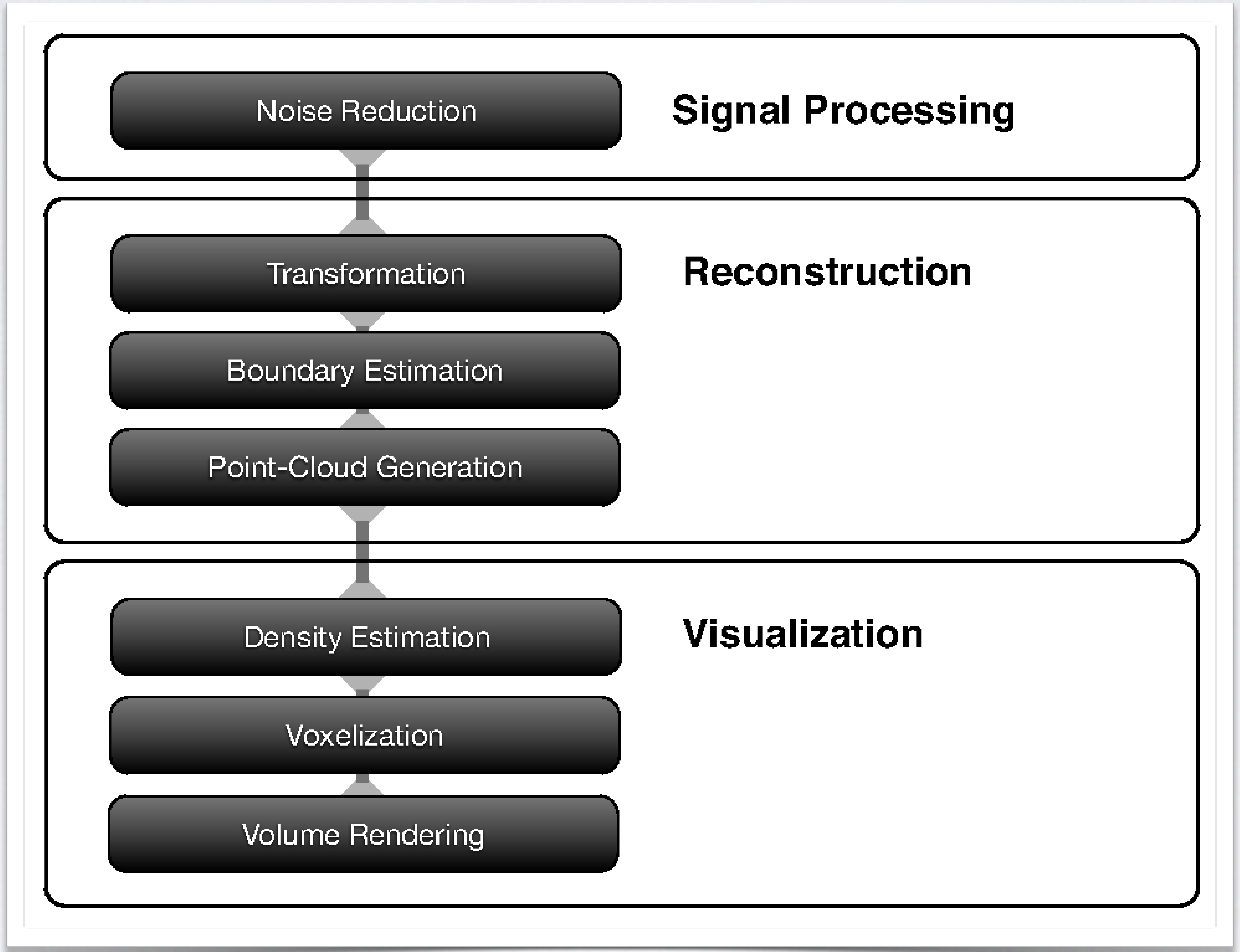
APPROACH

- **OUT-OF-CORE STREAMING DATA MANAGEMENT**
  - Continuous processing using recordings from live scans
  - Use streaming I/O and structured data layout
  - Overlap data prefetching with computation
  - Adjust data stream size to balance load

APPROACH

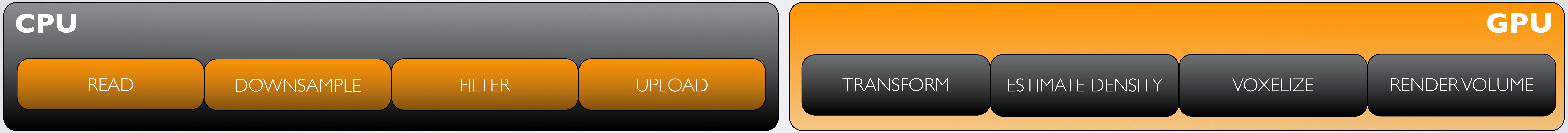
- **HETEROGENOUS PARALLEL PROCESSING**
  - Use multi-core CPUS to handle streaming I/O and data layout
  - Use GPU for on-the-fly incremental reconstruction and rendering

WORKFLOW

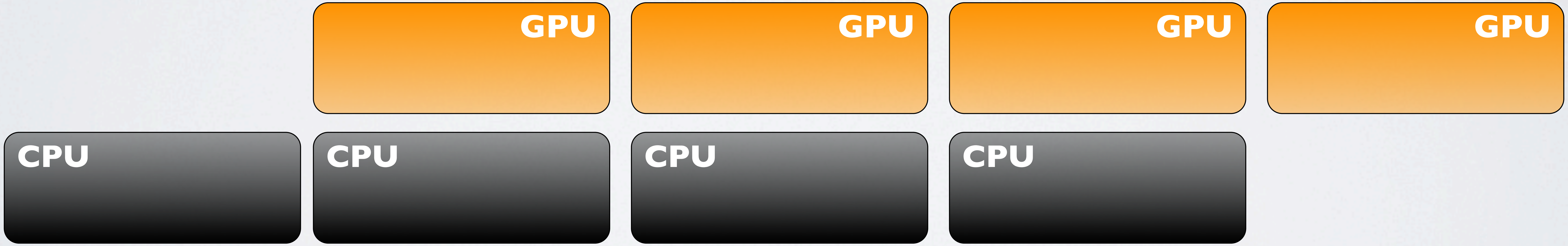

Noise Reduction
Signal Processing
Transformation
Reconstruction
Boundary Estimation
Point-Cloud Generation
Density Estimation
Visualization
Voxelization
Volume Rendering

WORKFLOW

PIPELINE



SCHEDULING



SIGNAL PROCESSING

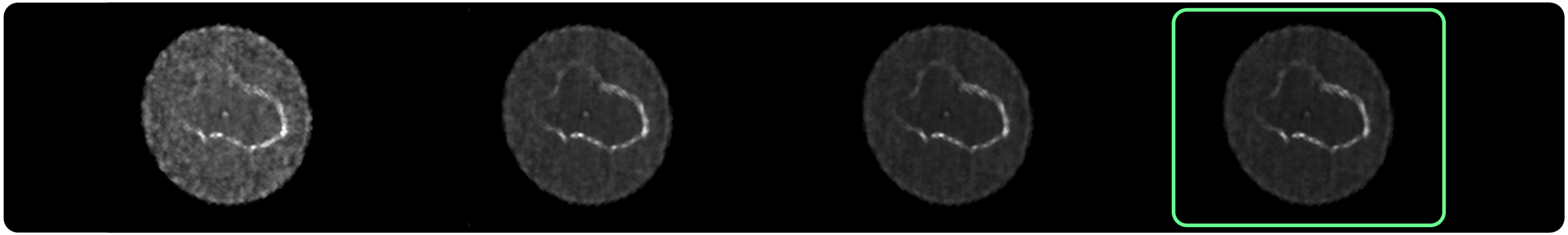
- **DOWNSAMPLING**
  - Reduce raw data based on spatial feature size
- **FILTERING**
  - Use 1D sliding window to reduce background noise

Algorithm 1 Background Noise Reduction Filter

$sum \leftarrow 0$
$count \leftarrow 1$
$a \leftarrow AScanIntensityIndex$
for $i = a - dx$ to $a + dx$ **do**
    if $i >= 0$ and $i < AScanLength$ **then**
        $sum+ = Intensity(ascan, i)$
        $count+ = 1$
    end if
end for
$v \leftarrow Intensity(ascan, a)$
$ave \leftarrow sum\ /\ count$
$v \leftarrow ave > v\ ?\ (MinSignal * v) : v$
$Output(ascan, a, v)$

SIGNAL PROCESSING

BACKGROUND NOISE REDUCTION



***dx* = 5** **dx = 10** **dx = 15** **dx = 20**

WINDOW SIZE (***dx***)

TRANSFORM SETUP

- **TRANSFORM MATRIX**
  - Create concatenated transformation matrix based on calibration information and magnetic tracker information
- **ESTIMATE BOUNDARY**
  - Compute min/max extents by transforming start & end points

Algorithm 2 A-Scan Transform Matrix

while $a \leftarrow ReadNextAScan()$ **do**
    $t \leftarrow ReadTrackerInfo(a)$
    $m \leftarrow CreateTransformMatrix(t)$
    $Output(m)$
end while

POINT TRANSFORM

- **POINT-CLOUD GENERATION**
  - Transform each AScan sample into the global reference frame as point-based contributions
  - Store world position and reflectance intensity contribution for each point

Algorithm 3 Point Transform

```
while a ← ReadNextAScan() do
    m ← ReadTransformMatrix(a)
    for i = 0 to EndOfAScan(a) do
        v ← Intensity(a, i)
        p ← Transform(m, i)
        Output(p, v)
    end for
end while
```

DENSITY ESTIMATION

- **WEIGHTED CONTRIBUTIONS**
  - Use smooth particle hydrodynamics based filtering technique (*Cha et al*)
  - Weight samples by distance and intensities of neighbouring particles (Lanczos-Sinc filter) and project onto dense voxel grid stored as a texture

SPH Based Density Estimation Kernel

$$\rho_i = \rho(\mathbf{r}_i) = \sum_j m_j W(\mathbf{r}_i - \mathbf{r}_j, h)$$

Lanczos-Sinc Filter

$$L(x) = \begin{cases} sinc(x)sinc(x/a) & \text{if } -a < x < a, x \neq 0 \\ 1 & \text{if } x = 0 \\ 0 & \text{otherwise .} \end{cases}$$

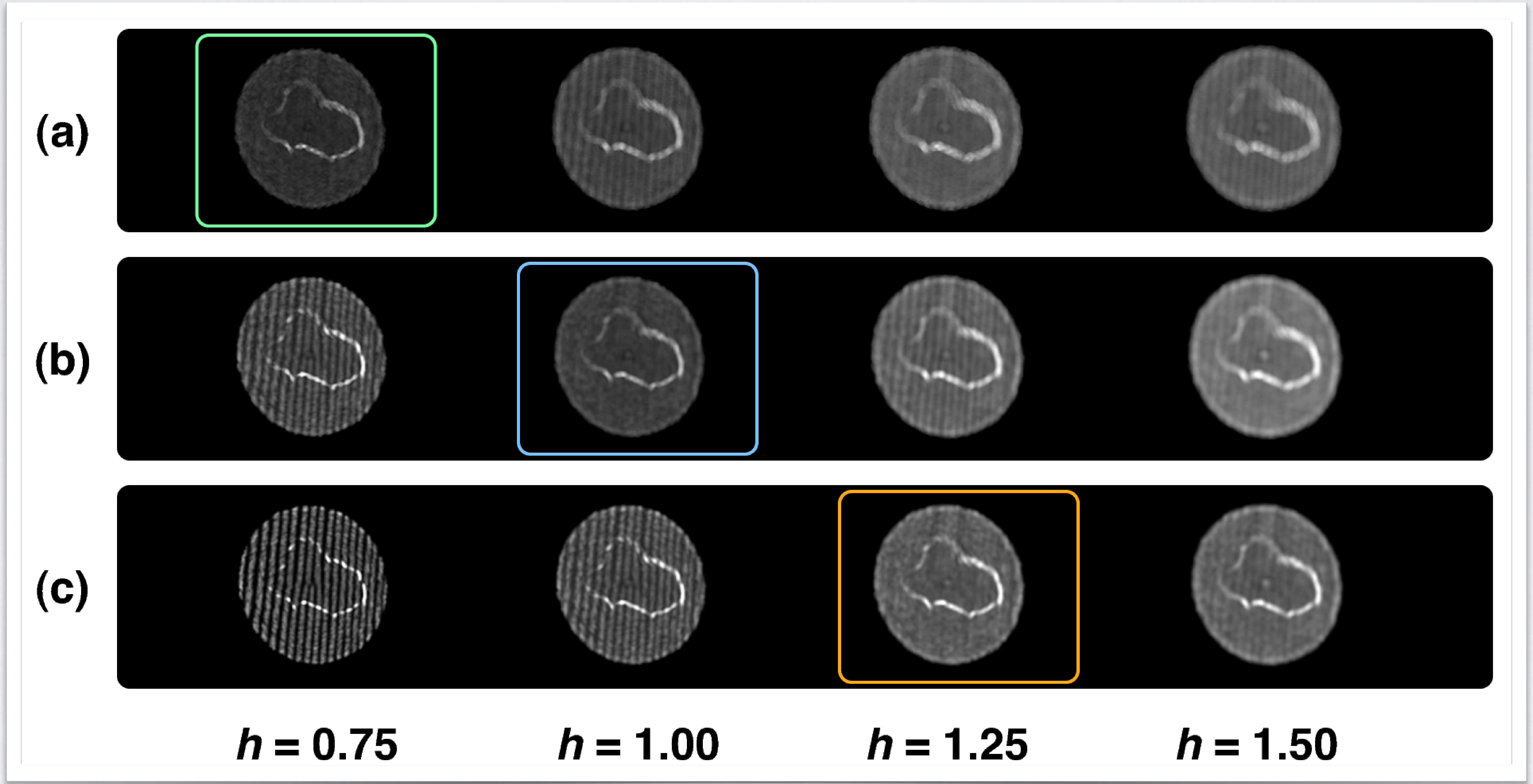
D. Cha, S. Son, and I. Ihm. Gpu-assisted high quality particle rendering. Eurographics Symposium on Rendering, pages 1–9, May 2009.

DENSITY ESTIMATION

LANCZOS-SINC

SMOOTH-POLY

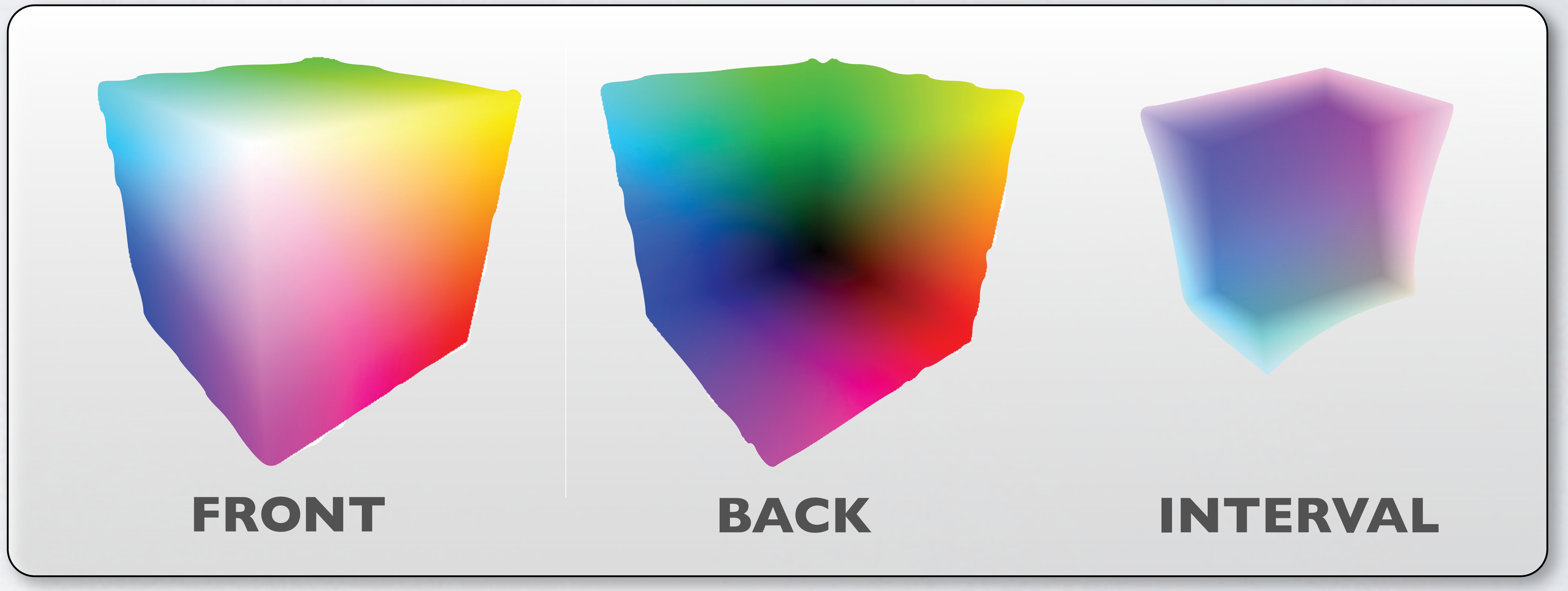
POLY6

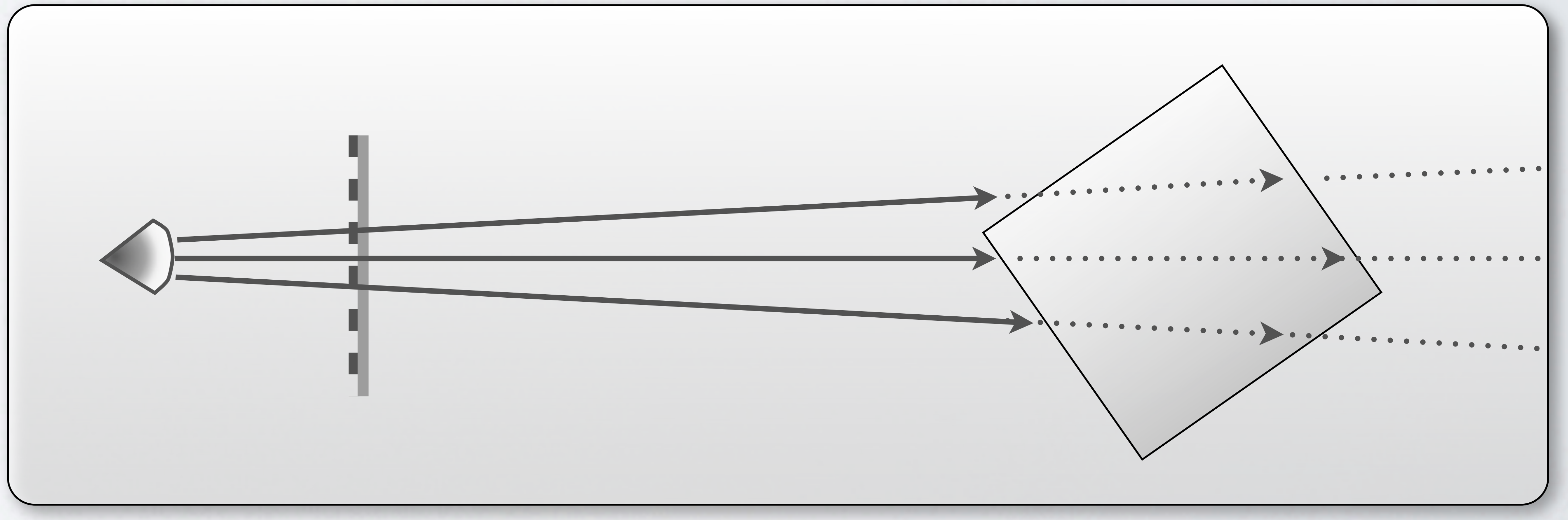


SMOOTHING DISTANCE (***h***)

VOLUME RENDERING

- **VOLUME RAYCASTING**
  - Use standard approach of rasterising bounding cube to generate primary rays (*Scharsach et al*)
  - Accumulate opacity by integrating along ray at fixed intervals and sampling volume texture at each step

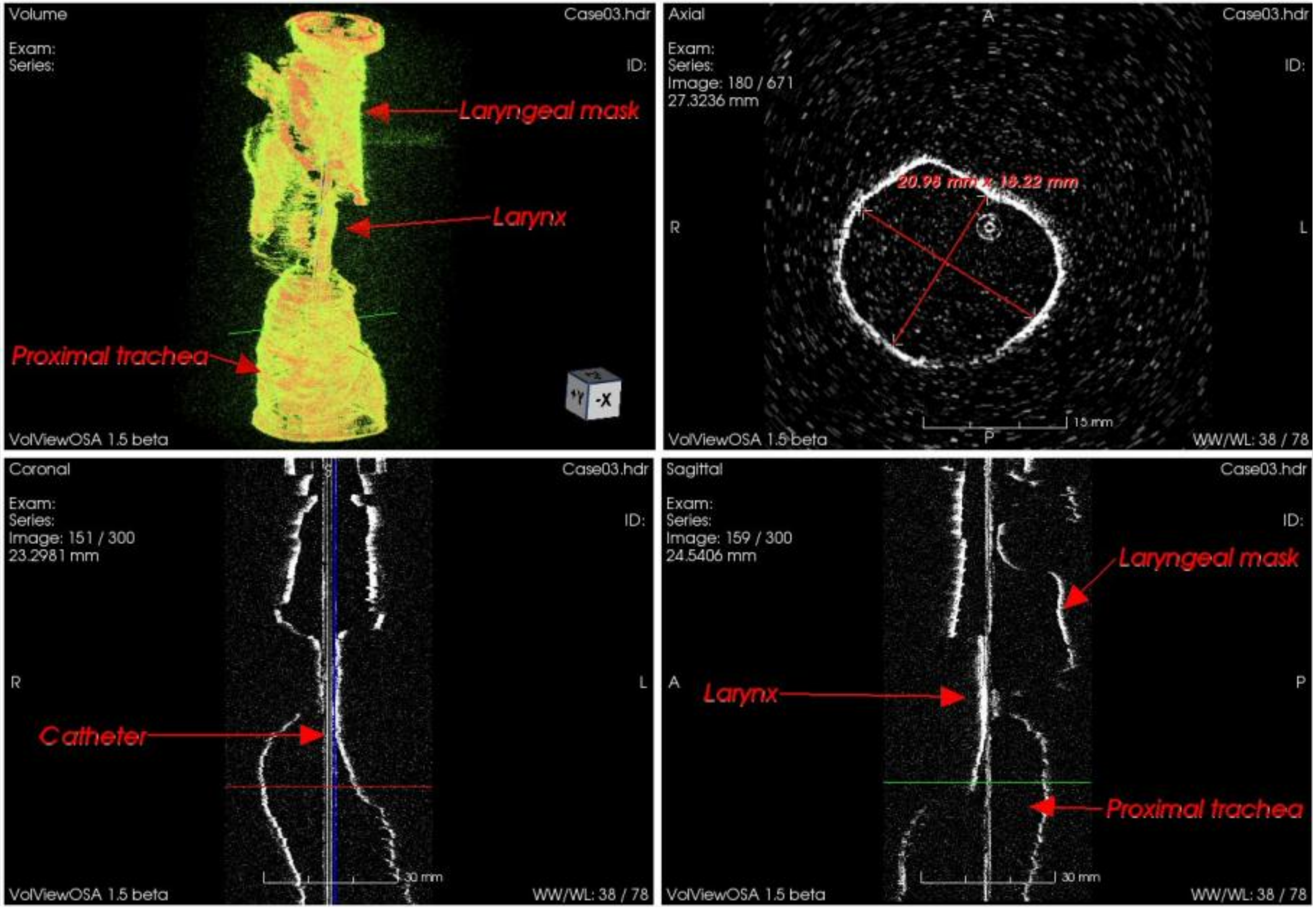




H. Scharsach. Advanced raycasting for virtual endoscopy on consumer graphics hardware, 2005.

VALIDATION

- **APPROACH**
  - Create a phantom of the lower portion of the human airway with an artificially introduced narrowing to model a stenosis
  - Compare caliper measurements of phantom to reconstructed volume measurements for accuracy
  - Use scan acquisition time for base-level performance requirement



Volume
Case03.hdr
Exam:
Series:
ID:
Laryngeal mask
Larynx
Proximal trachea
+Y
-X
VolViewOSA 1.5 beta
Axial
A
Case03.hdr
Exam:
Series:
Image: 180 / 671
27.3236 mm
ID:
20.98 mm x 18.22 mm
R
L
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Image: 159 / 300
24.5406 mm
ID:
Laryngeal mask
A
P
Larynx
Proximal trachea
30 mm
VolViewOSA 1.5 beta
WW/WL: 38 / 78

IMPLEMENTATION

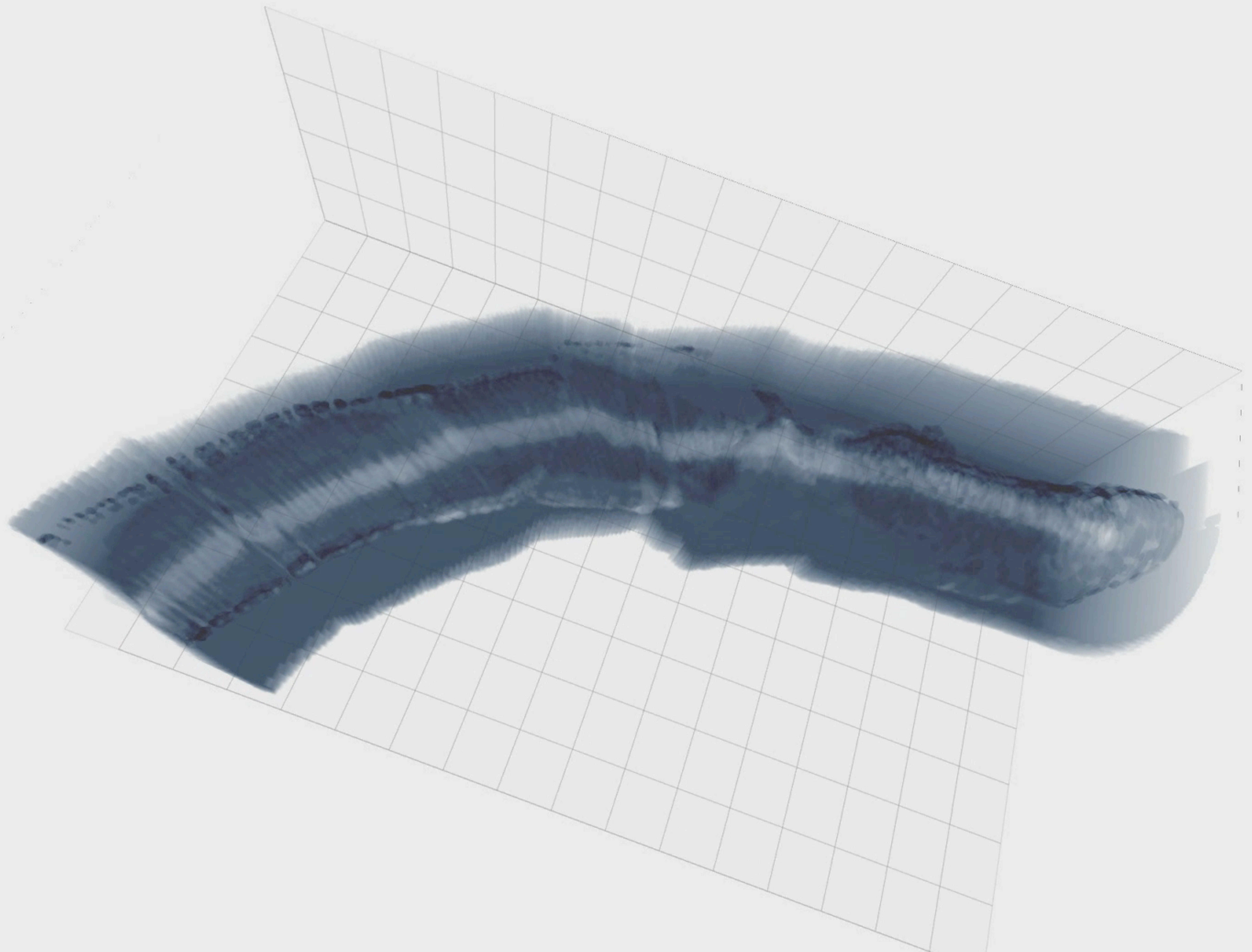
- **HETEROGENOUS PROCESSING**
  - Use **OpenCL** on Mac OSX which allows intermixing kernel and task execution for coordinating CPU and GPU execution via event wait-lists
- **COMBINED GRAPHICS & COMPUTE**
  - Use **OpenGL** bindings to allow seamless updates from **OpenCL**

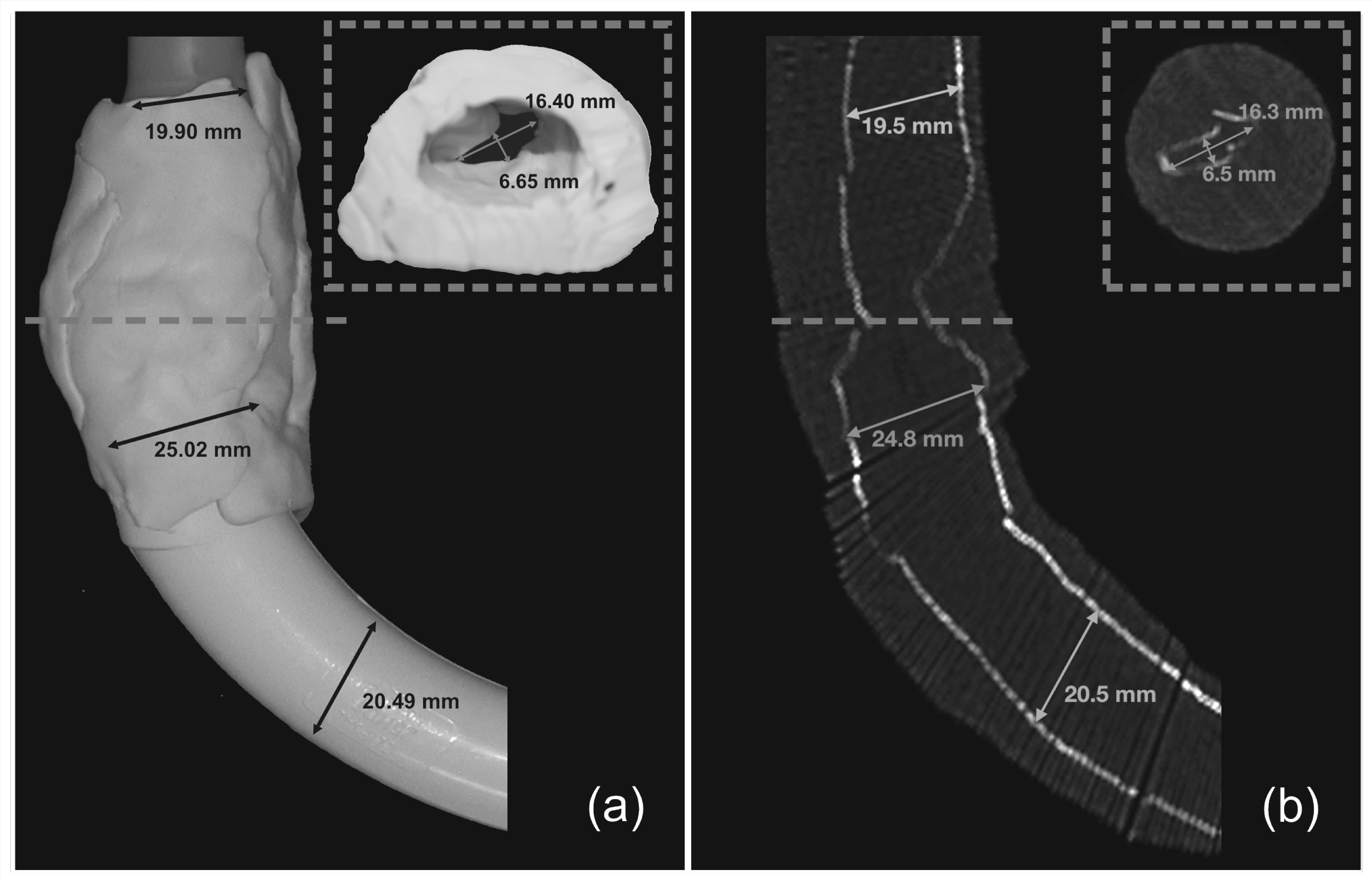
IMPLEMENTATION

- **SYSTEM CONFIGURATION**
  - Apple Mac Pro 2009 w/2x Intel Xeon X5570 2.25Ghz (8-core / 16-threads)
  - NVIDIA GTX-285 w/768 MB
- **SOFTWARE SPECIFICS**
  - ANSI-C99 compiled with GCC v4.2.1 with -O3 flags

RESULTS


0.00 mm
24.00 mm
48.00 mm
72.00 mm
96.00 mm
120.00 mm
144.00 mm





16.40 mm
6.65 mm
19.90 mm
25.02 mm
20.49 mm
(a)
19.5 mm
16.3 mm
6.5 mm
24.8 mm
20.5 mm
(b)

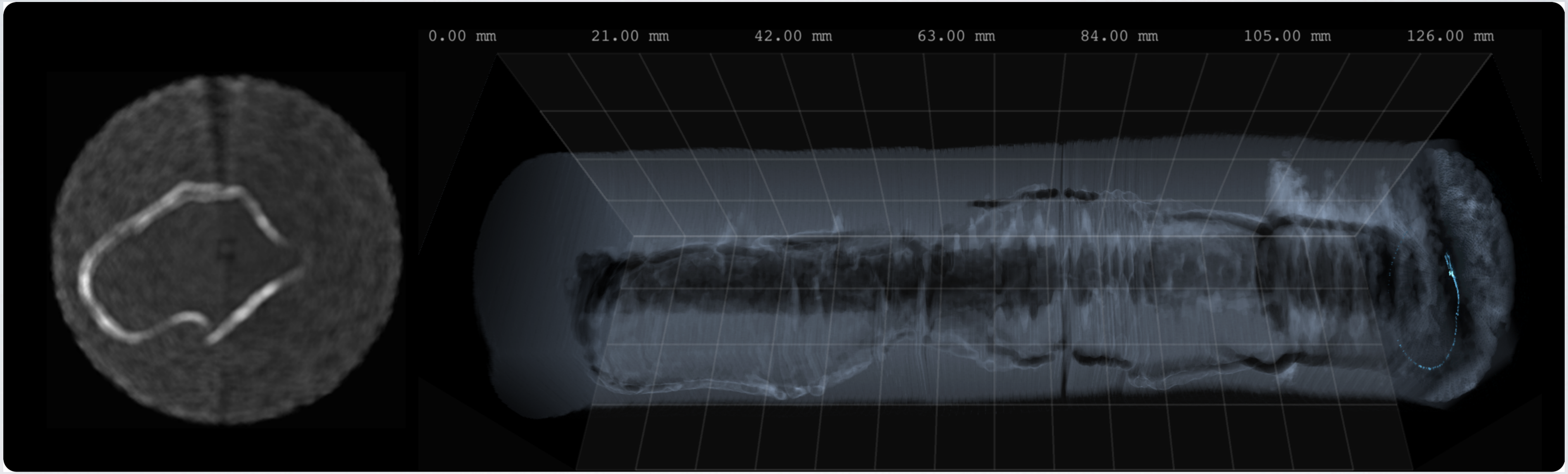
VALIDATION

Table 1. Accuracy Assessment

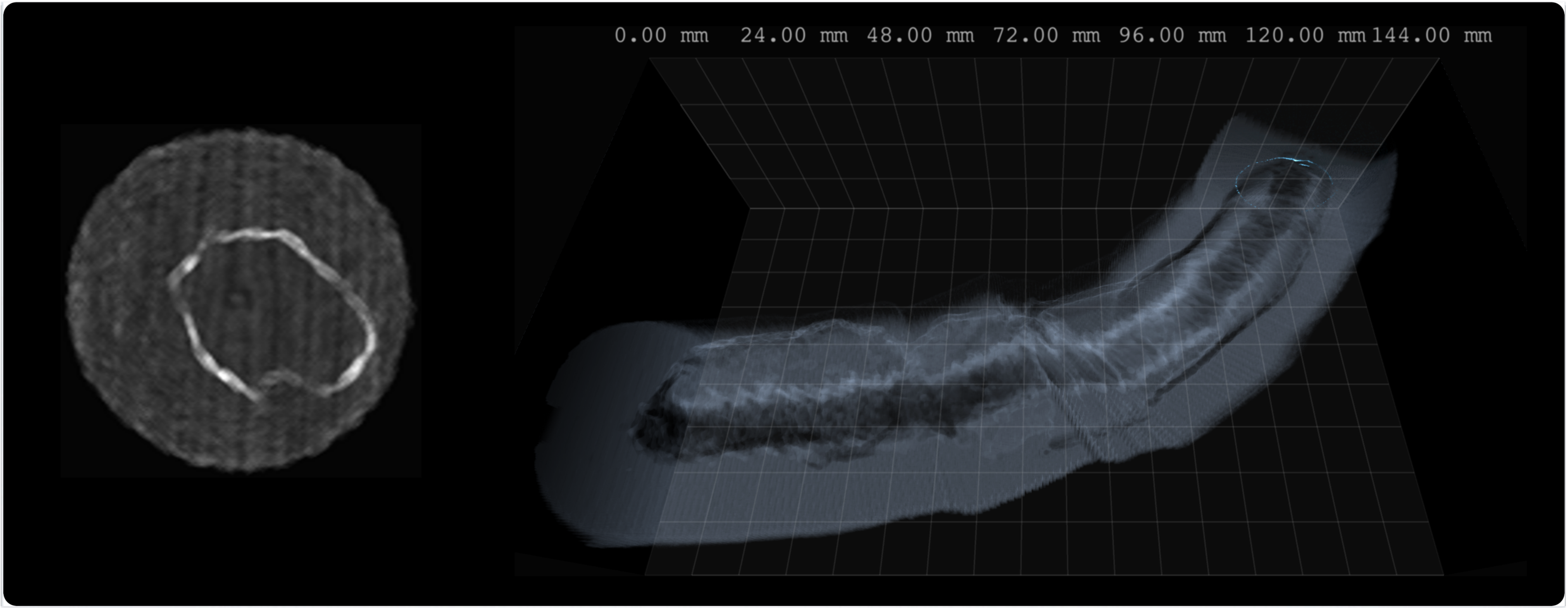
Measurement Location	Physical	Reconstructed	Percent Error
Minor Diameter (Stenosis)	6.65 (+/- 0.51) mm	6.50 (+/- 0.40) mm	-2.3%
Major Diameter (Stenosis)	16.40 (+/- 0.43) mm	16.30 (+/- 0.40) mm	-0.6%
Start Diameter (PVC)	19.90 (+/- 0.08) mm	19.50 (+/- 0.40) mm	-1.4%
Middle Diameter (PVC)	25.02 (+/- 0.11) mm	24.48 (+/- 0.40) mm	-2.2%
End Diameter (PVC)	20.49 (+/- 0.38) mm	20.50 (+/- 0.40) mm	+0.05%

Average Error	Root-Mean Squared
-1.39%	1.68%

WITHOUT 3D TRACKER



WITH 3D TRACKER



PERFORMANCE

Table 2. Performance Analysis

Resolution	Memory	Points	Radius	Framerate	Compute
64	132 MB	192k	0.75	30 FPS	45.0 sec
128	172 MB	192k	0.75	30 FPS	78.0 sec
256	478 MB	192k	0.75	30 FPS	245.0 sec

SCAN ACQUISITION TIME (***110 sec***)

LIMITATIONS

- **CONSTRAINED**
  - Limited to available hardware and proprietary file formats
- **UNOPTIMISED**
  - Experimental implementation done as a prototype
  - Plenty of room for performance improvements

LIMITATIONS

- **COMPRESSION**
  - Currently reading raw uncompressed data directly from the scanner
- **SAMPLING**
  - Reduced acquisition time at the cost of under-sampling
  - Could use the physical optical parameters to improve reconstruction

FUTURE WORK

- **ULTRA-SCALE**
  - Apply techniques towards massive volume visualisation distributed across many machines in a cluster environment
- **DISTRIBUTED RESOURCE MANAGEMENT**
  - Currently looking at load-balancing, scheduling, and programming concepts to deal with the problems inherent with targeting heterogenous cluster environments

QUESTIONS?

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Perth GPU Users

HTTP://WWW.MEETUP.COM/PERTH-GPU-USERS