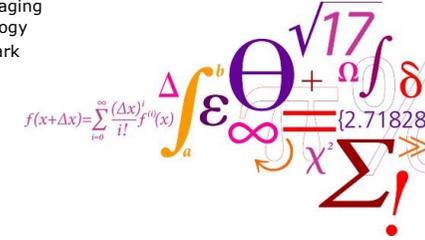


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CFU research Part 2: Fast Vector Flow Imaging, Super Resolution and 3D VFI

Jørgen Arendt Jensen

Center for Fast Ultrasound Imaging
Department of Health Technology
Technical University of Denmark

$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$


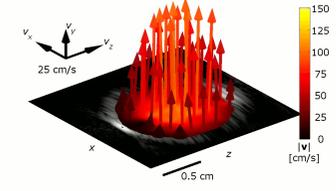
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Department of Electrical Engineering

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Front-line research in Ultrasound

- Can we measure 3-D flow fast with only 124 transducer elements?
- Can we break the speed-accuracy trade
- Can we see brain function and epileptic attack?
- Can we resolve structures below the resolution limit?



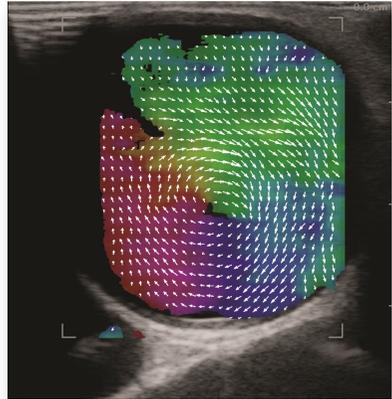
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Systolic blood flow in ascending aorta of a patient with aortic valve stenosis (short axis view)



Hansen et al. *Ultrasonic Imaging*, Vol. 35, No. 4, 2013

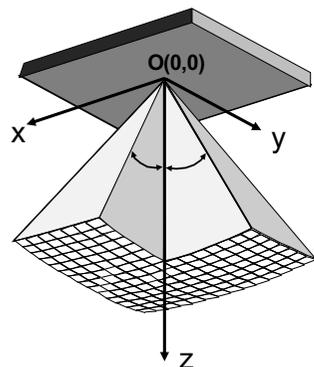
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3-D Imaging and Matrix Probes




32 x 32 = 1024 element
Matrix Probe from Vermon

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3D Measurement situation

- Cross-sectional scan of vessel:

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Measurement equipment

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Jensen et al. IEEE UFFC, No. 9, 2013

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SARUS experimental scanner

- 1024 channels and 70 MHz/12 bits sampling for 140 Gbytes/s
- Arbitrary transmission of coded signals
- 320 high-end FPGAs for real-time processing
- More than 128 Gbytes RAM for several seconds of data
- Capable of 25.600 billion mults/s
- Can perform real-time SA imaging at 32 frames/s

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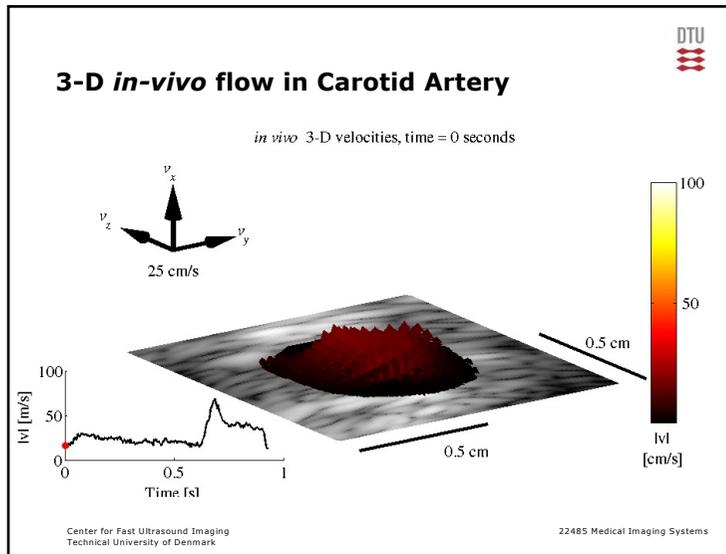
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3D vector flow image

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Denmark's Technical University DTU

Synthetic aperture and plane wave velocity imaging

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Limitations of current ultrasound systems

- Only one transmit focus
- Frame rate is limited especially for blood flow and 3D imaging

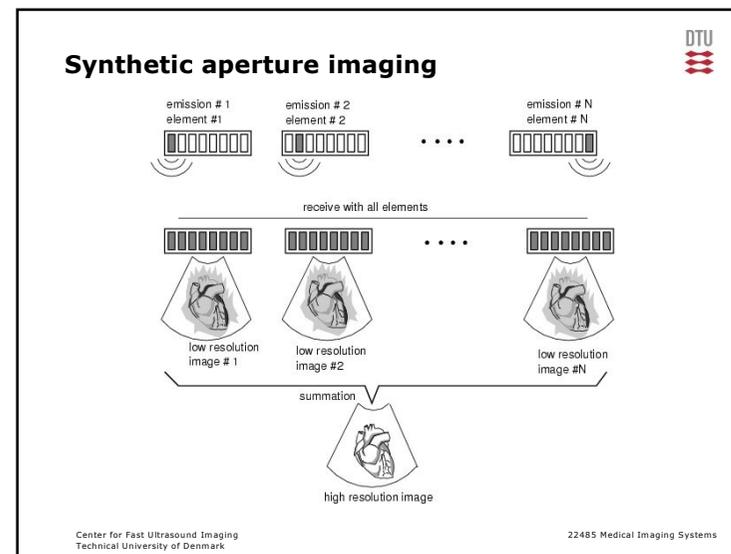
$$f_r = \frac{c}{2DN_d N_l} = \frac{1540}{2 \cdot 0.15 \cdot 100 \cdot 8} = 6 \text{ Hz}$$

- Velocity estimation is poor due to few data samples
- Velocity estimation is angle dependent - no transverse velocity can be estimated

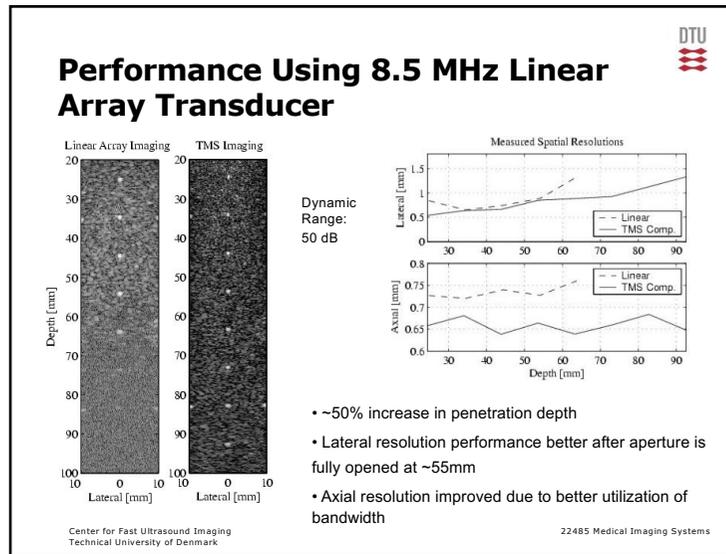
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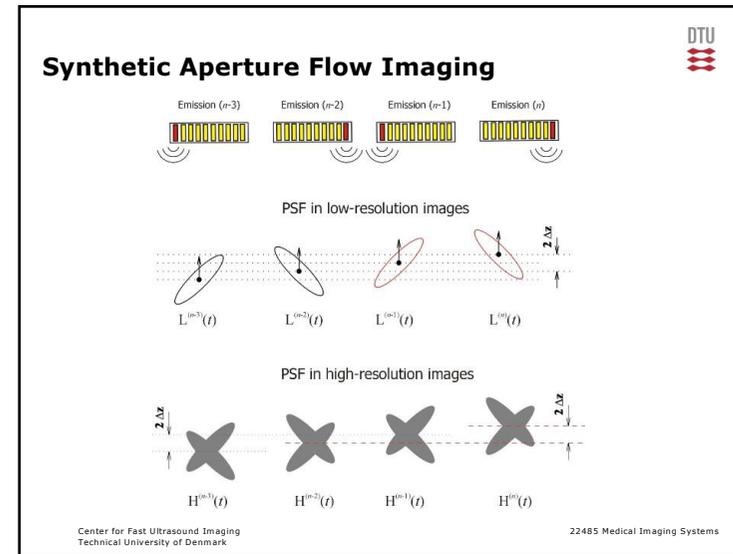
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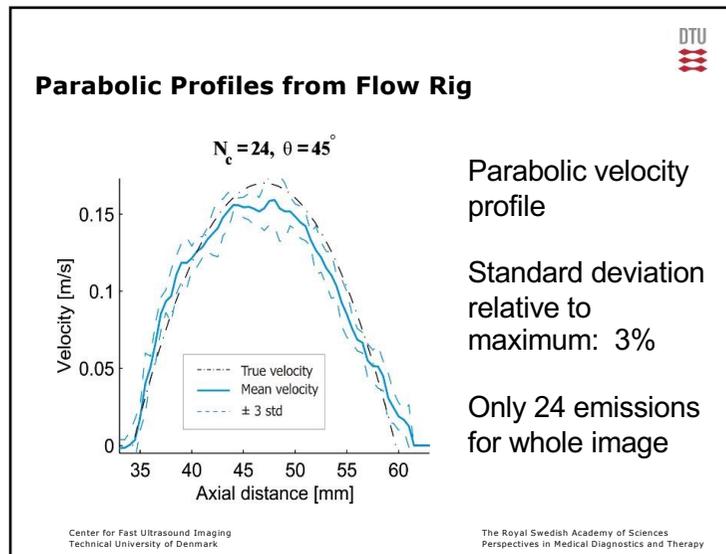
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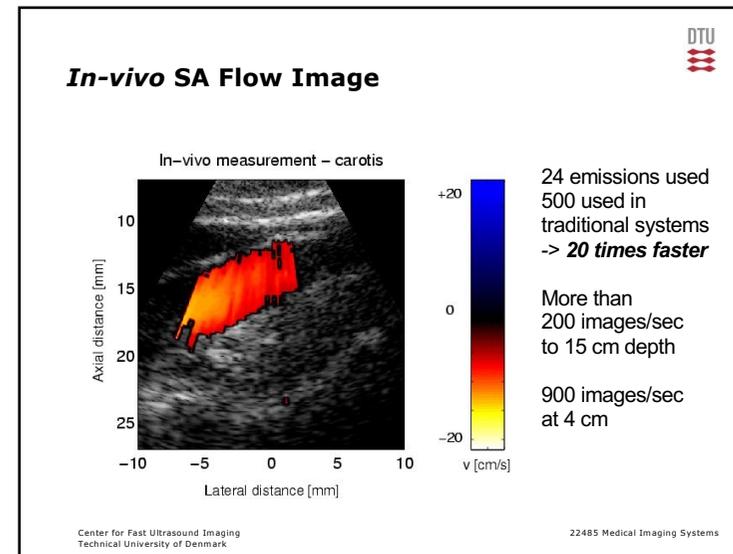
13



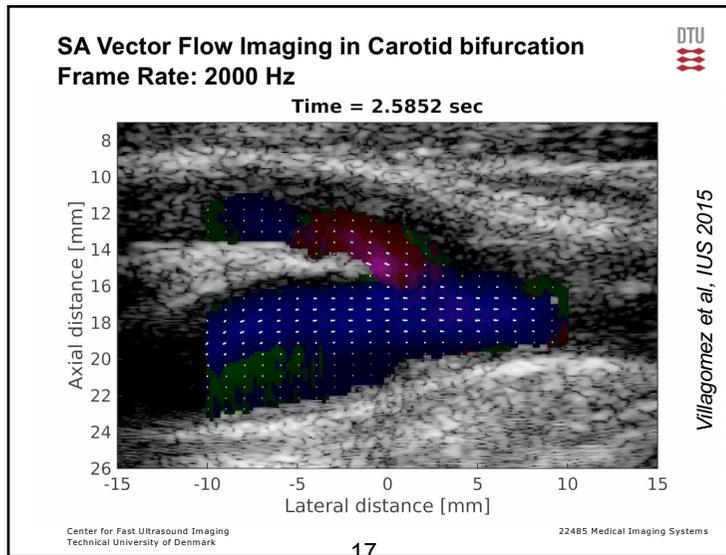
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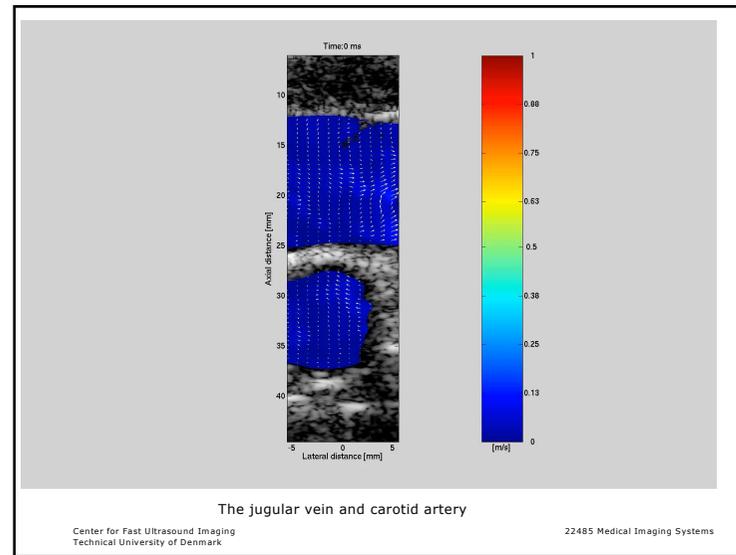
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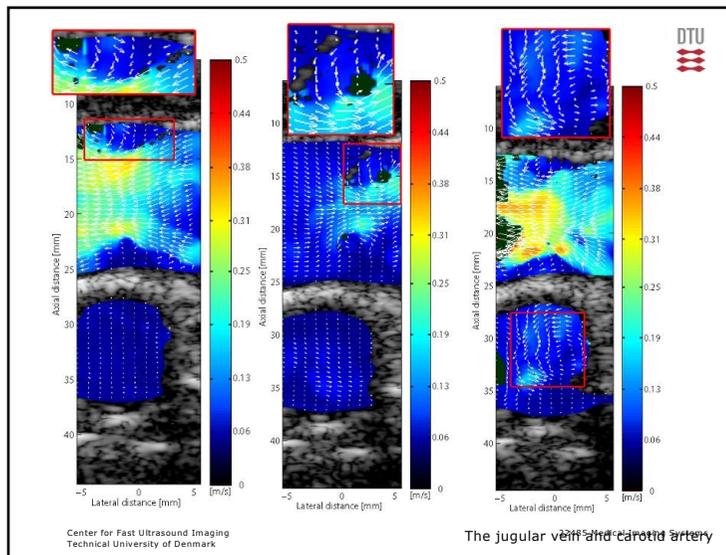
16



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Problem with Fully Populated Arrays

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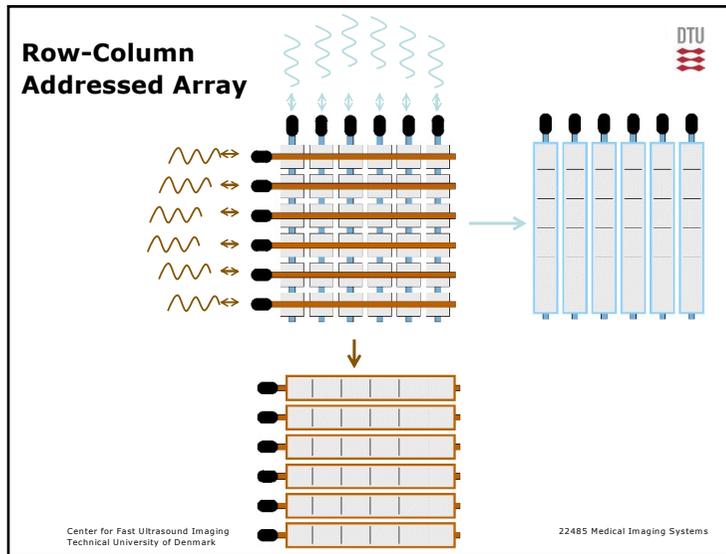
- 2D full array
- 1024 channels, should be 4096
- Expensive!

- New row-column Array prototype
- 124 channels
- Less expensive

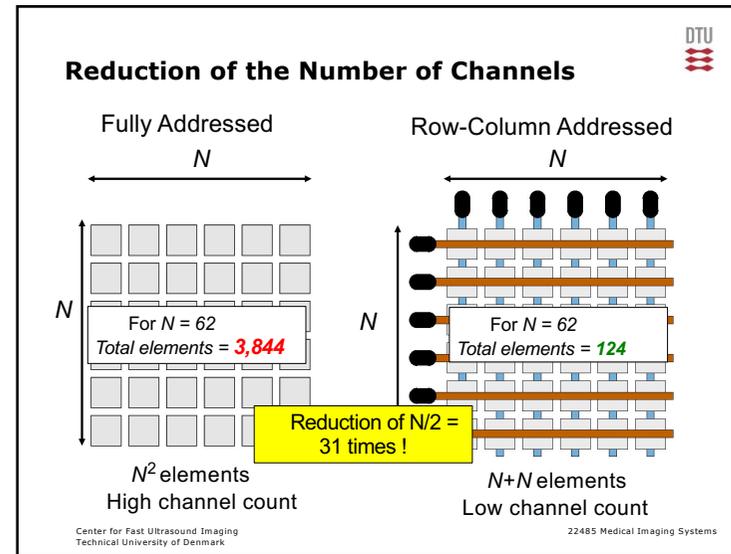
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Advantages of Row-Column Arrays

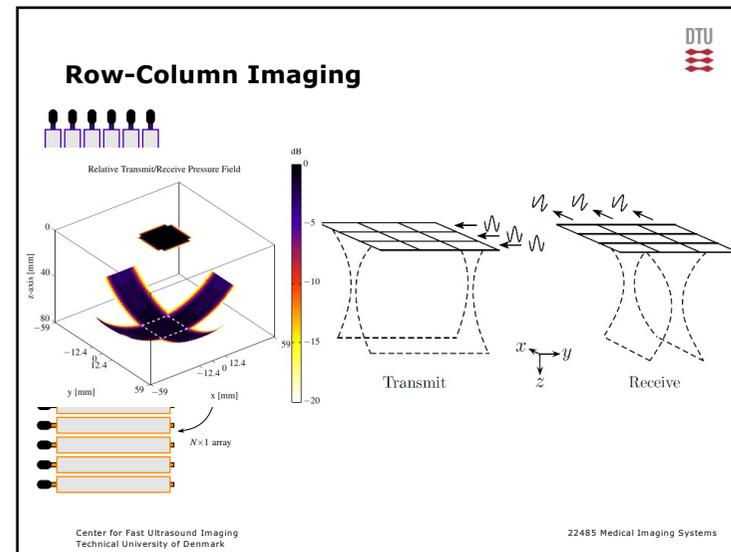
Matrix Array	RC Array
<ul style="list-style-type: none"> Focusing is dependent on N^2 <ul style="list-style-type: none"> Resolution: $FWHM = \lambda D/W = \lambda D/(N \text{ pitch})$ Double resolution leads to 4 times number of elements Penetration depth depends on area <ul style="list-style-type: none"> Many elements needed Sparse arrays suffer in penetration 	<ul style="list-style-type: none"> Focusing dependent on N <ul style="list-style-type: none"> Resolution scales linearly Double resolution – double number of elements Penetration depends on area <ul style="list-style-type: none"> Area = $(N \text{ pitch})^2$ Double number of elements gives four times area



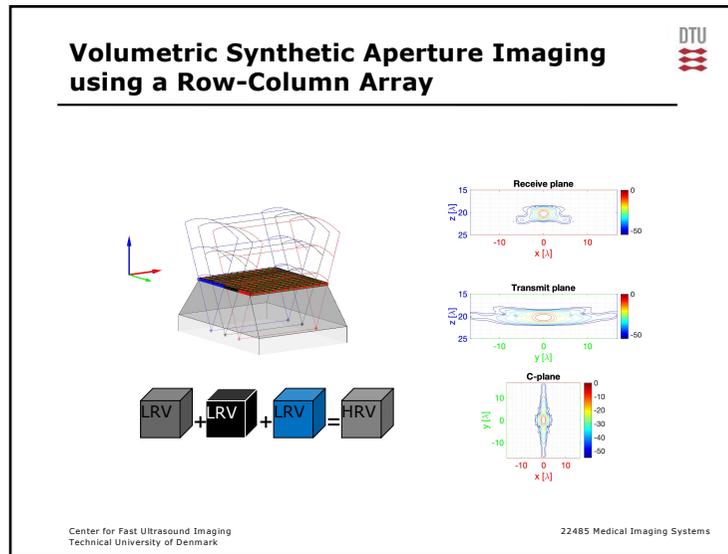

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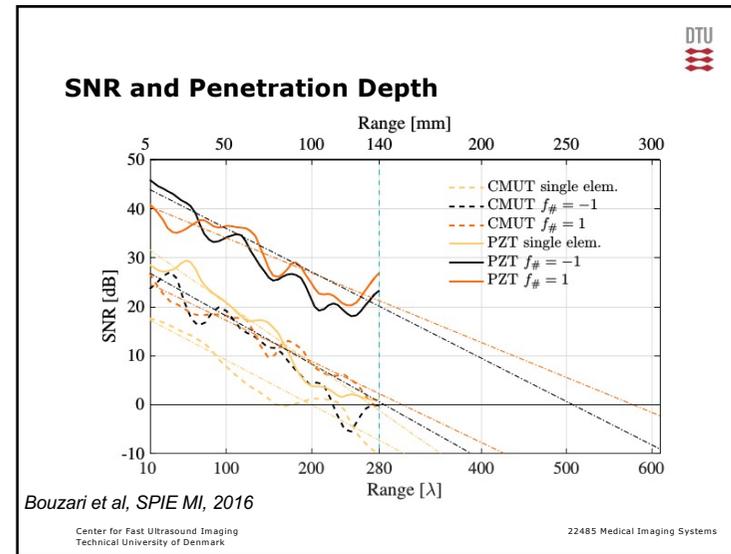
23



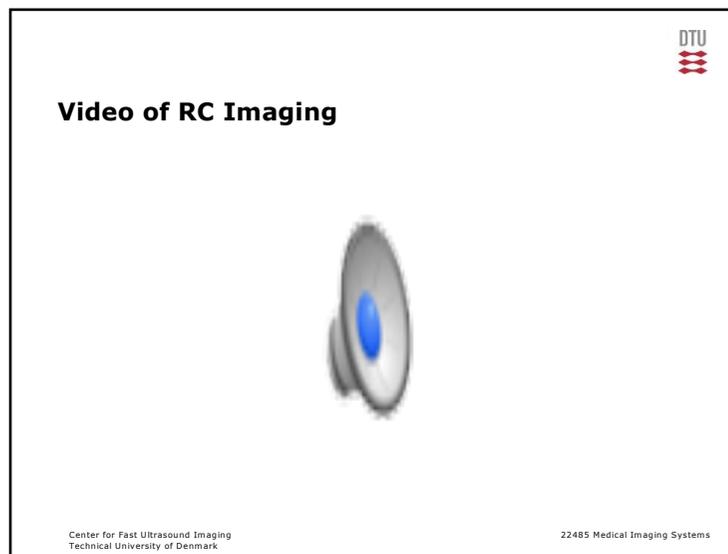
24



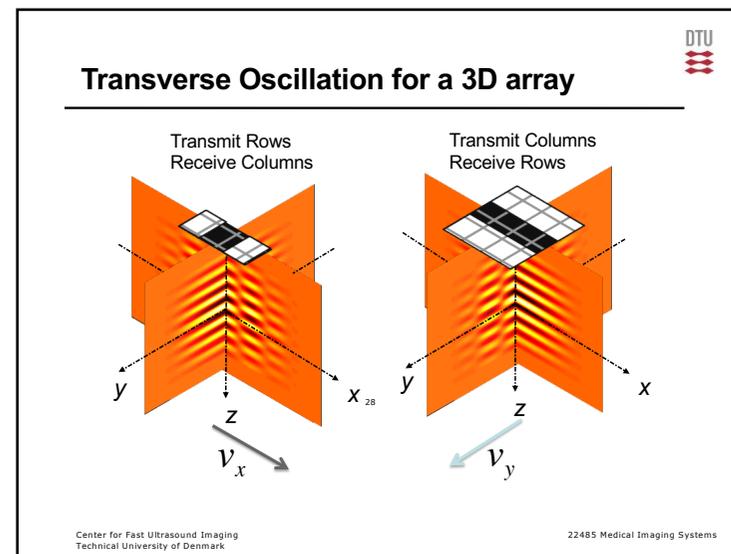
25



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Sequence

3 MHz, 62 + 62, Row Column array, piezoelectric, experimental probe
 Contains 80 emissions; 4 flow blocks (16 emissions), 16 B-mode emissions
 Volume rates
 B-mode: 125 Hz @ 10 kHz PRF
 VFI: 250 Hz @ 10 kHz PRF

V_x V_y V_x V_y

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Simulation setup for 62+62 row-column array

- Carotid bifurcation flow simulated using CFD
- CFD output transferred to Field II

Simulation parameters	
Pulse cycle duration	1.2 s
Peak inlet velocity	80 cm/s
Non-rigid walls	Yes
Acquisition parameters	
Number of elements	62+62
Pitch	0.27 mm
Center frequency	3 MHz
Number of emissions	12
Transmit/receive	-2/1
F#	
Pulse repetition frequency	10 kHz

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Row-column vector flow in carotid bifurcation

Actual velocity

Estimated velocity

Frame rate: >200 Hz

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Row-column vector flow in carotid bifurcation

Actual velocity

Estimated velocity

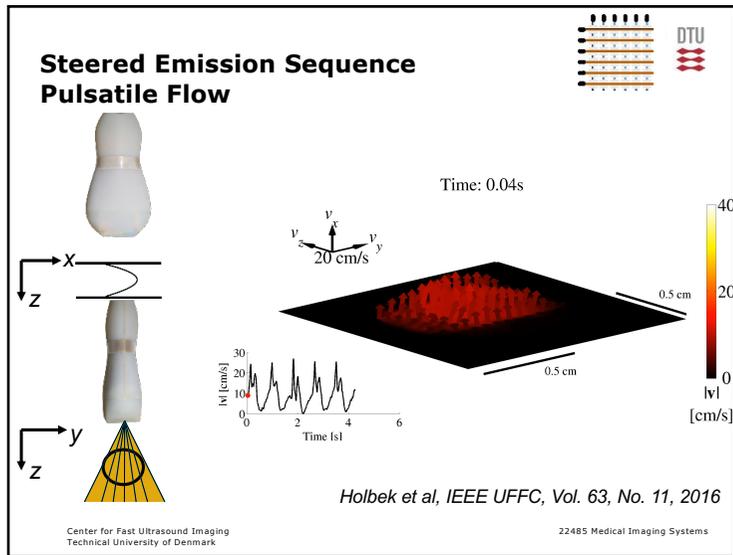
Frame rate: >200 Hz

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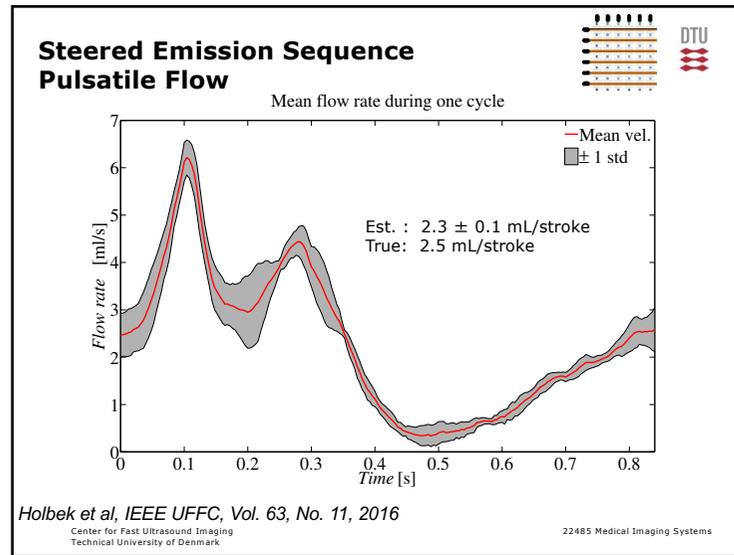
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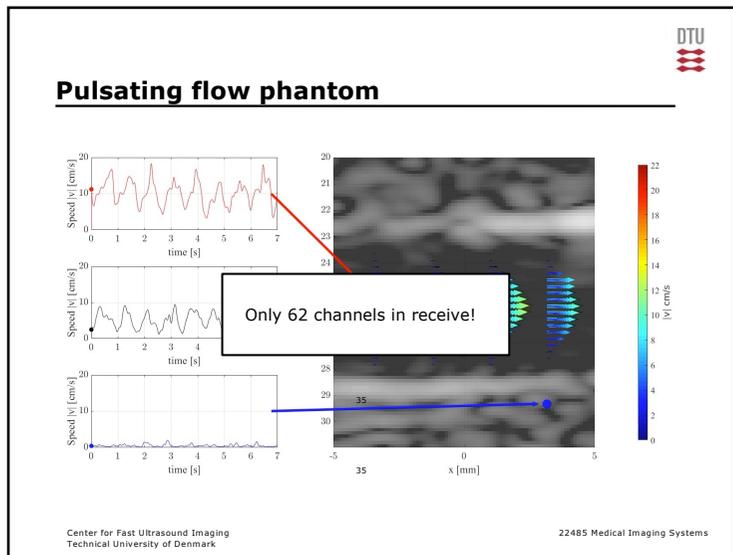
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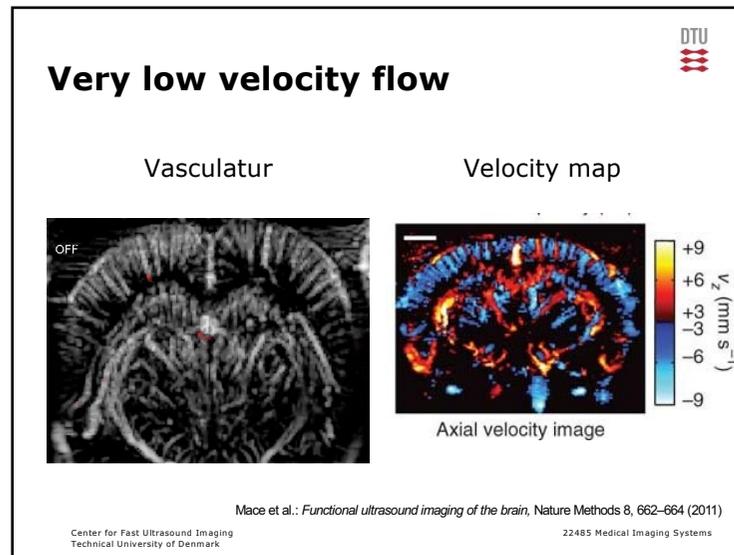
33



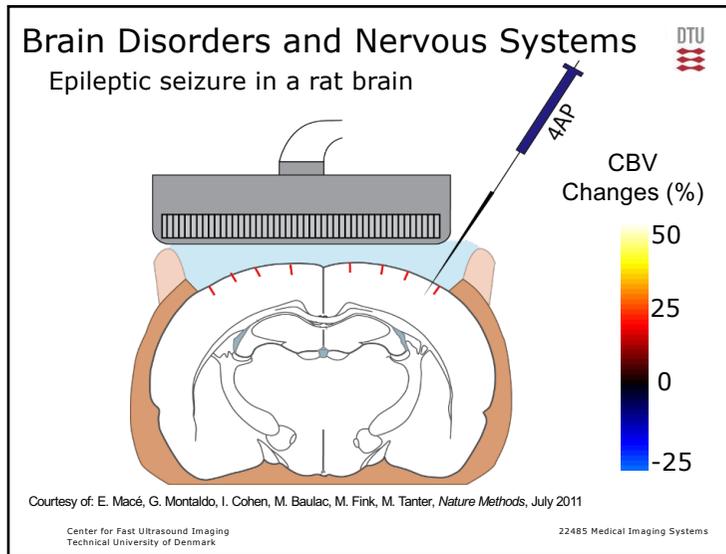
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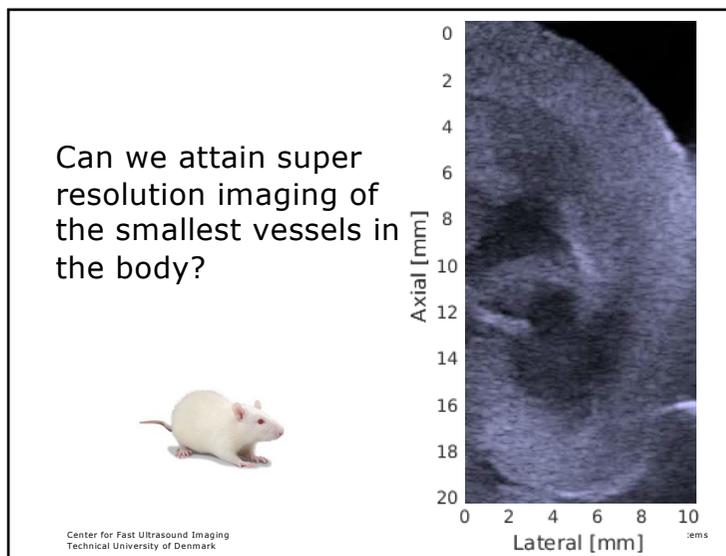
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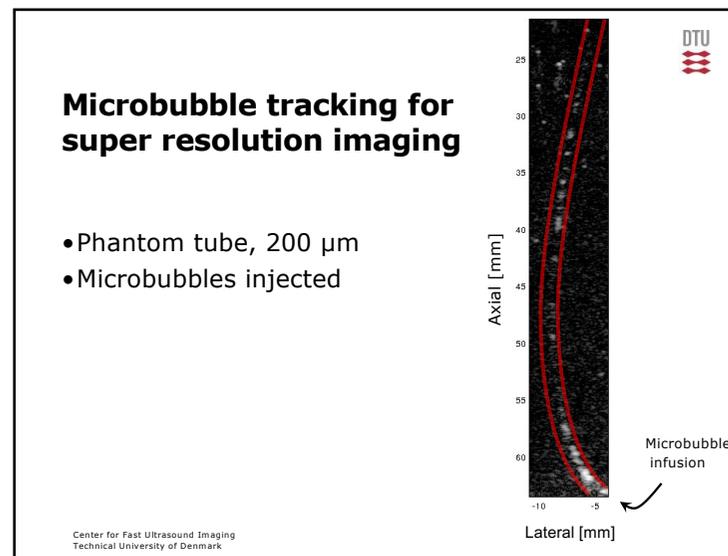
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Microbubble Characteristics

- Diffraction -> Point Spread Function
- Weighted centroid -> Exact Position

*FWHM = Full Width at Half Maximum

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Super Resolution Imaging (SRI)

- Results in very high resolution images of micro vasculature
- Ultrasound imaging of gas-filled contrast agents (bubbles)
- Sparse distribution of bubbles
- Center of gravity found and tracks made from bubble flow

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Super Resolution Imaging (SRI)

Time: 0 min 0.19 s (frame: 10) (18 times speed-up)

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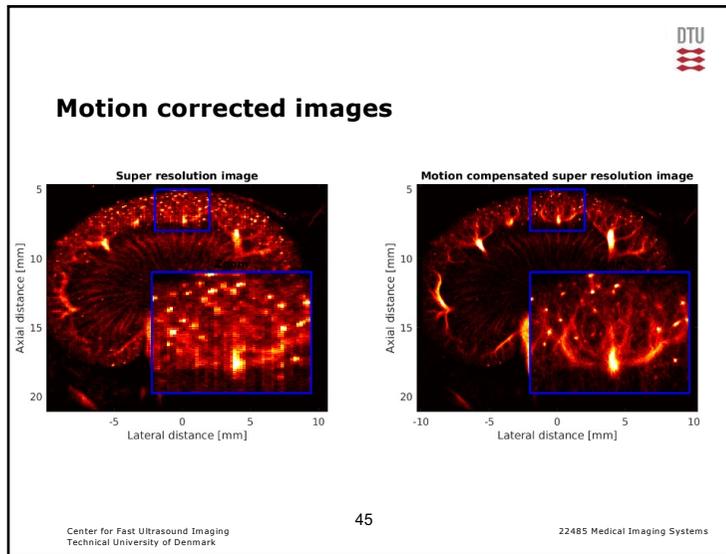
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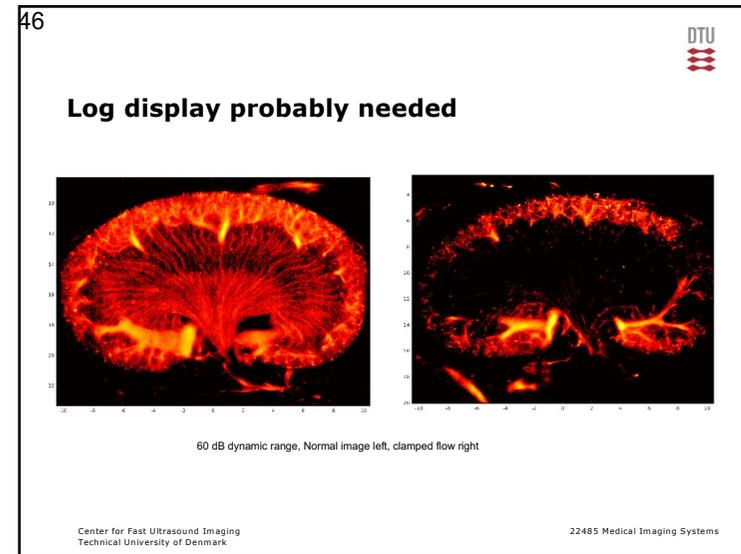
SR image for rate 7

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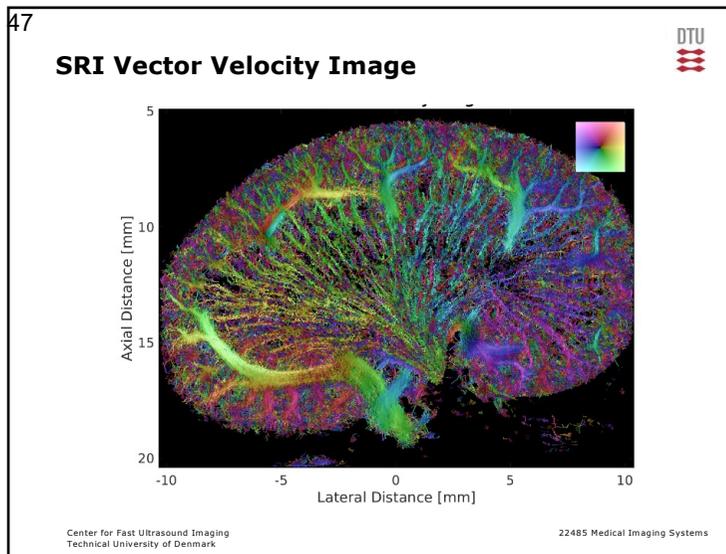
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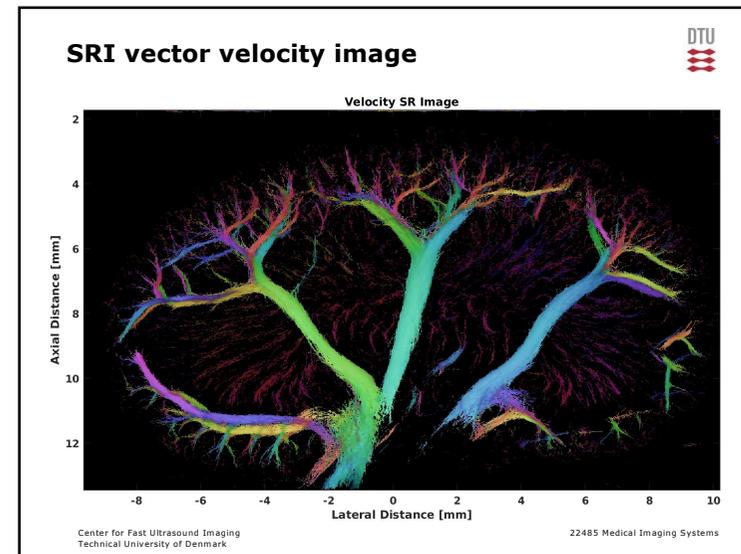
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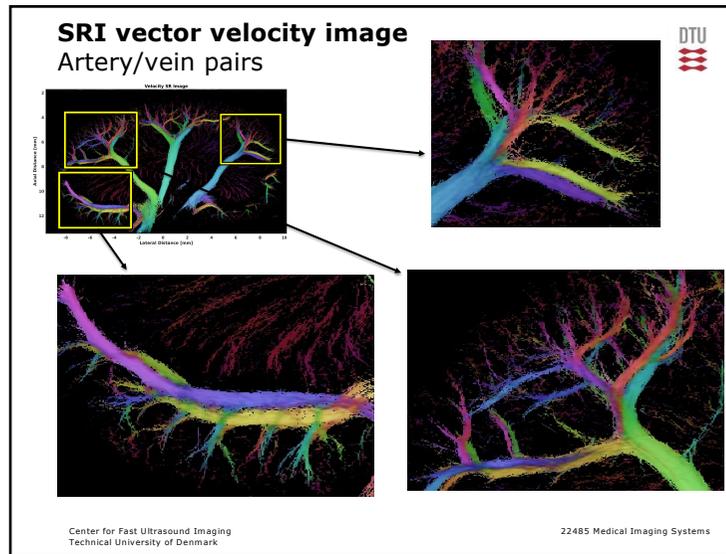
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SURE: Super Resolution ultrasound imaging using Erythrocytes

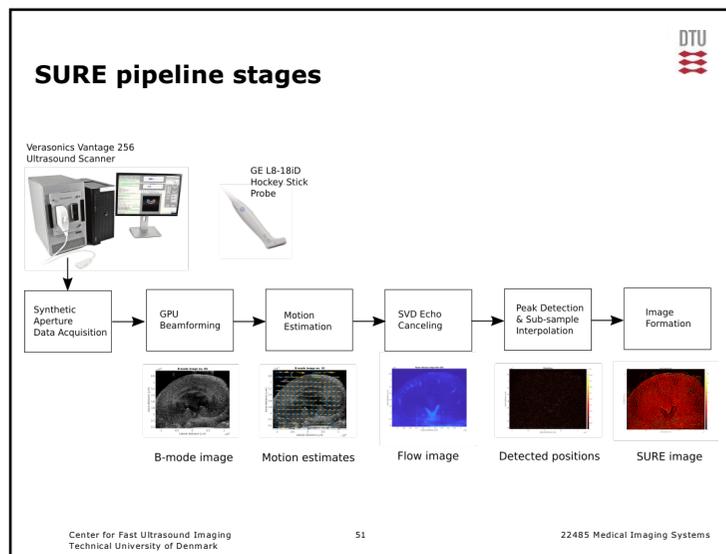
- Erythrocytes as tracking target:
 - Use advanced imaging to visualize the erythrocytes
 - Track speckle pattern to track motion
- Benefits
 - Abundance of targets
 - Full MI can be used
 - Fast imaging

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Scanning of Sprague-Dawley rats

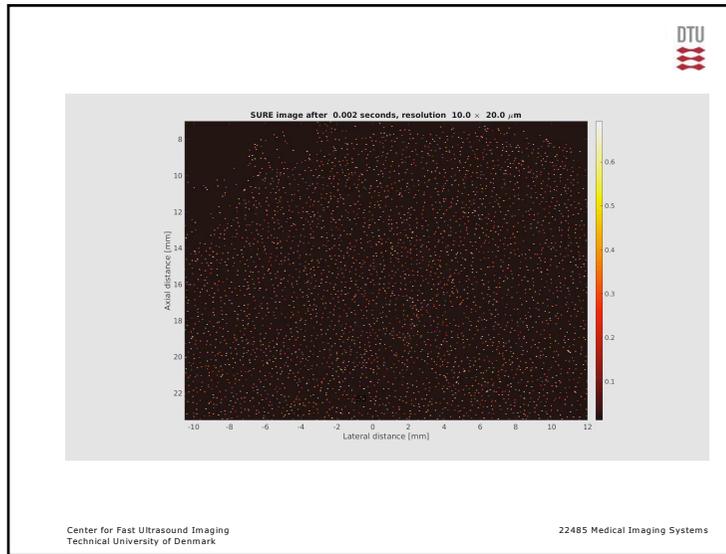
- 10 MHz scan frequency
- SA sequence with 12 emissions
- Frame rate of 416.7 Hz
- Verasonics Vantage 256 scanner
- GE L8-18i Hockey stick probe

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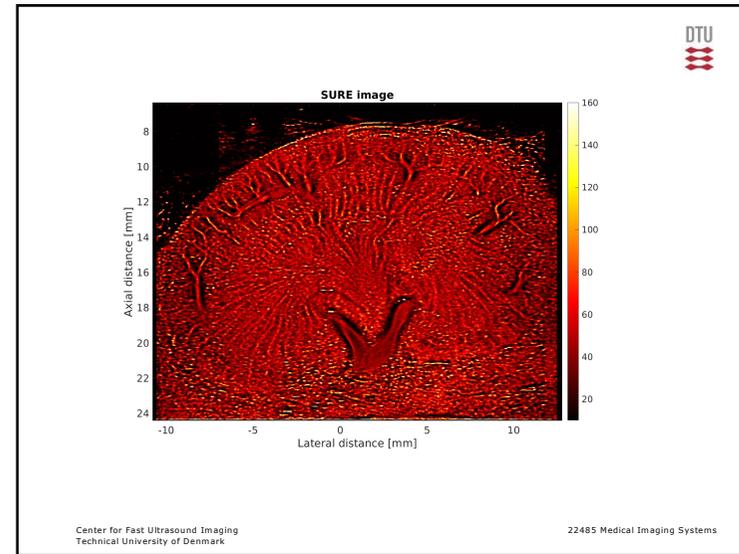
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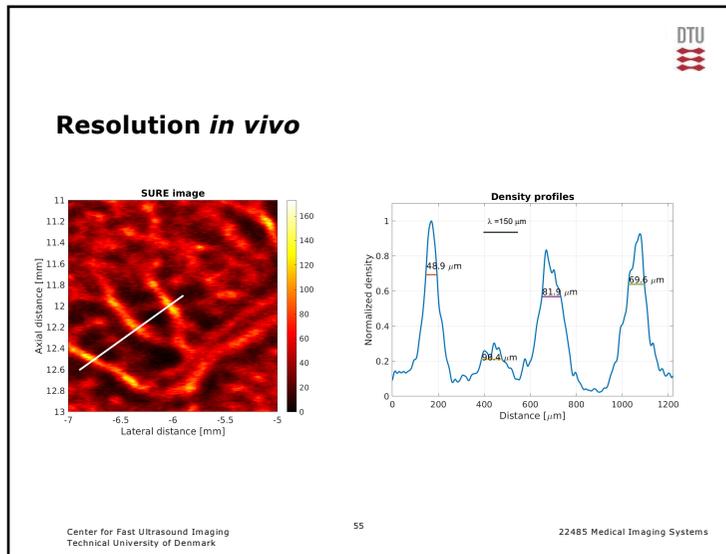
52



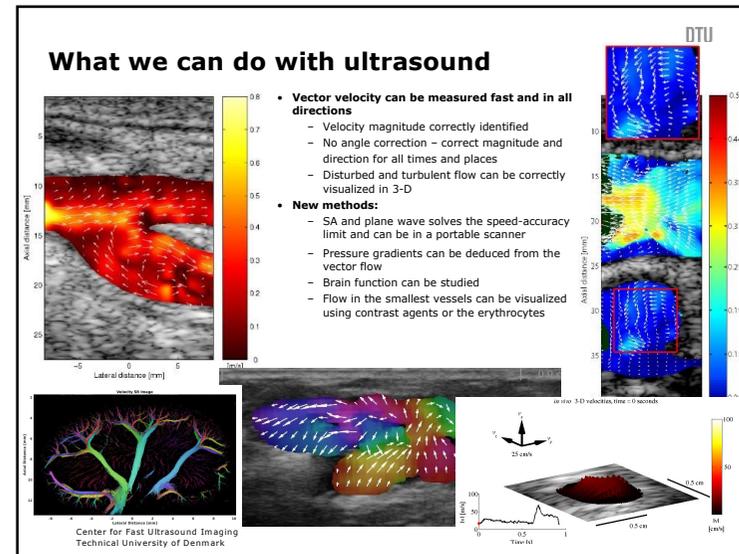
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Collaboration between: Many student projects
DTU Health Tech on these topics
Rigshospitalet
Panum – University of Copenhagen

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