AI* for blood flow with ultrasound

CSE 419A

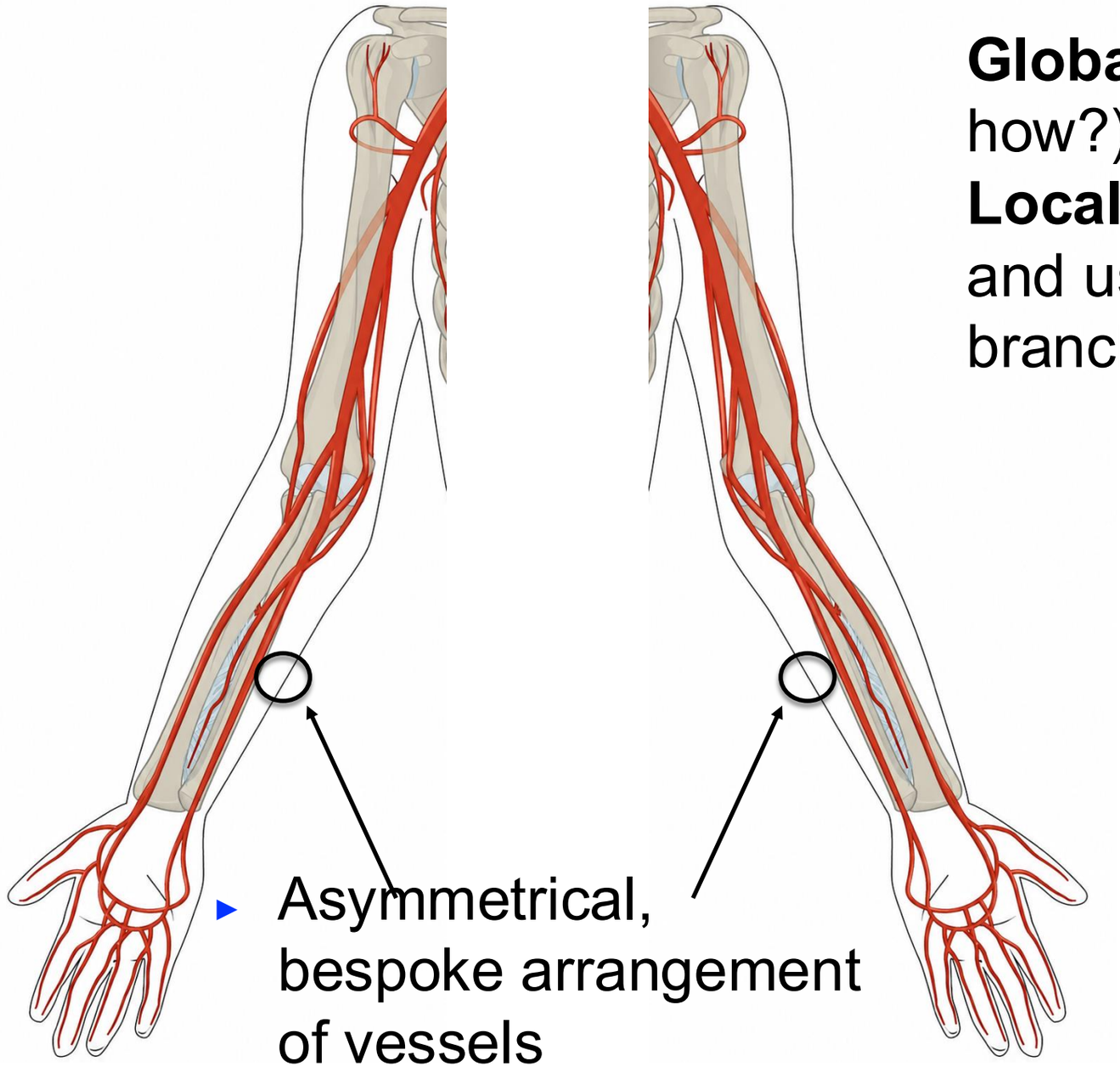
Edward Marti
November 5, 2026

*A challenge for AI efforts

Outline

1. Biological problem (vascular repair)
2. New technology (super-resolution ultrasound)
3. Challenge you to think about AI applications

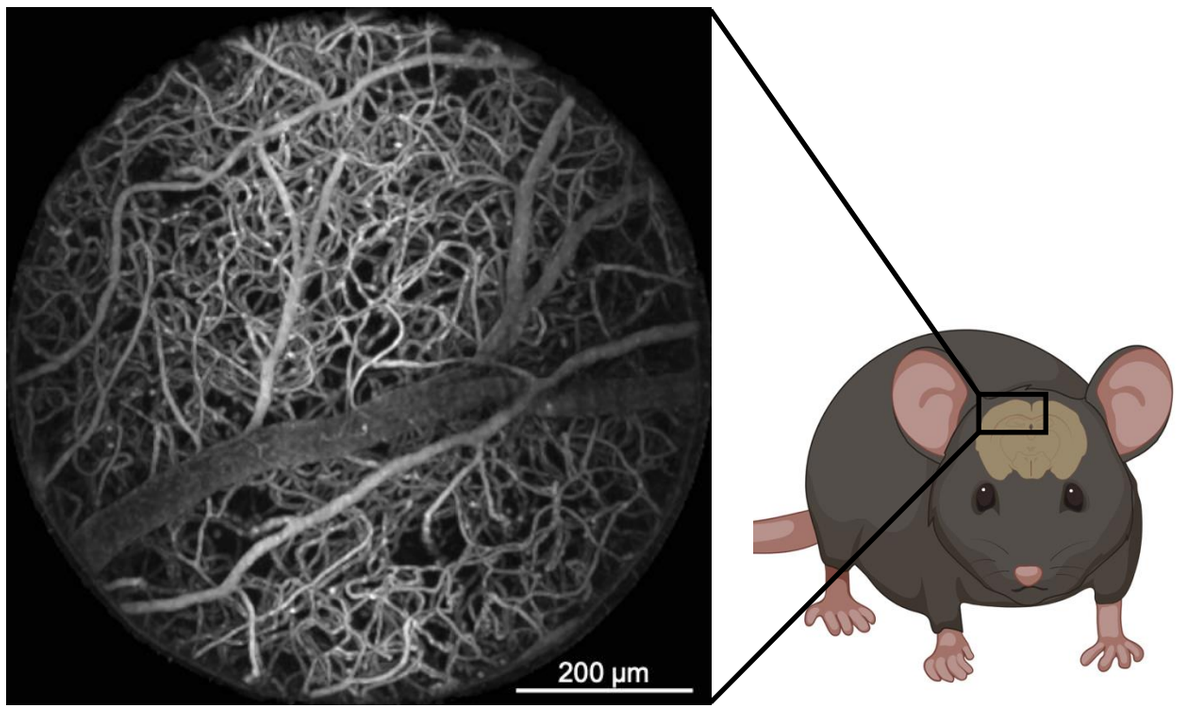
The vascular problem: deliver oxygen & nutrients, remove waste



- Asymmetrical, bespoke arrangement of vessels
- Every cell within ~100 µm of blood vessel

Wikimedia + ChatGPT

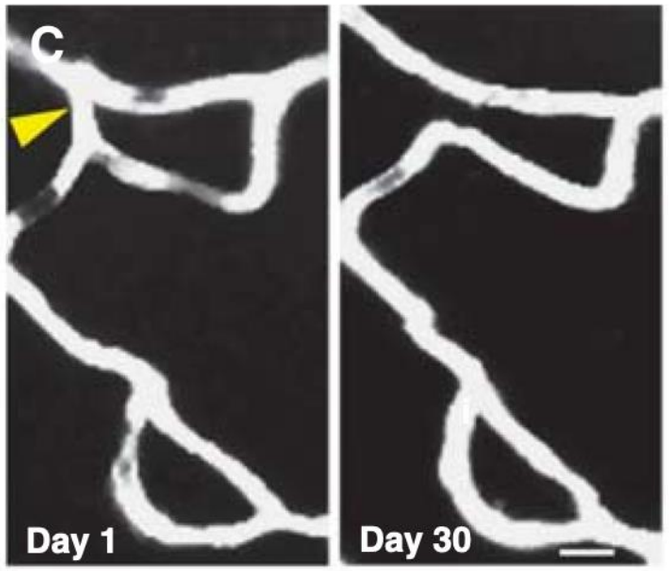
Global solution (>cm): genetics (but how?)
Local solution (10 µm-mm): cells sense and use simple rules: grow, regress, branch, etc.



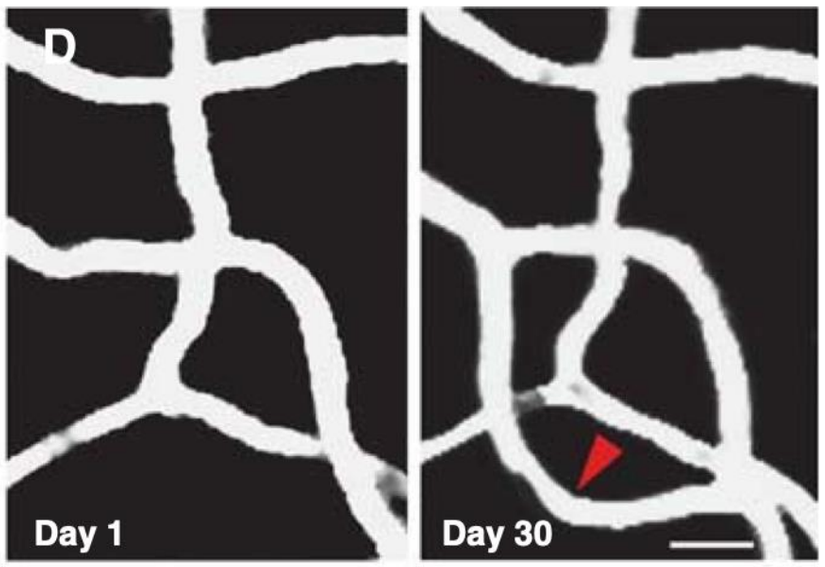
Ji, et al., *PNAS* **123**, e2521872123 (2026)

Vascular “computer” makes dynamic choices

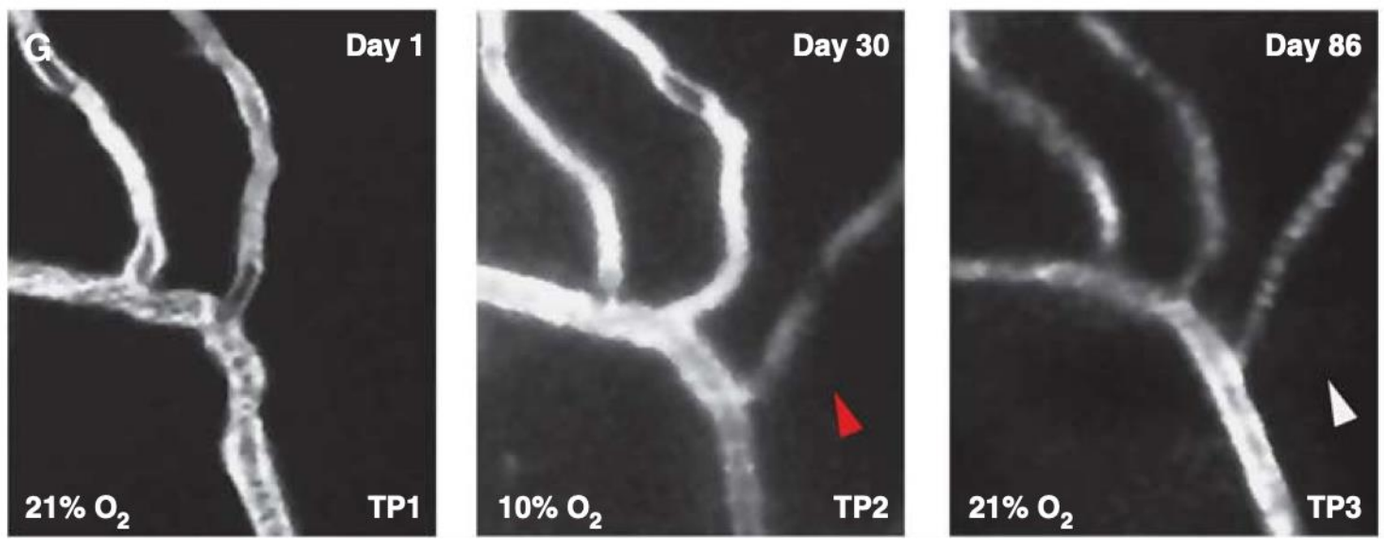
Brain of teenage-adult mice



Regression



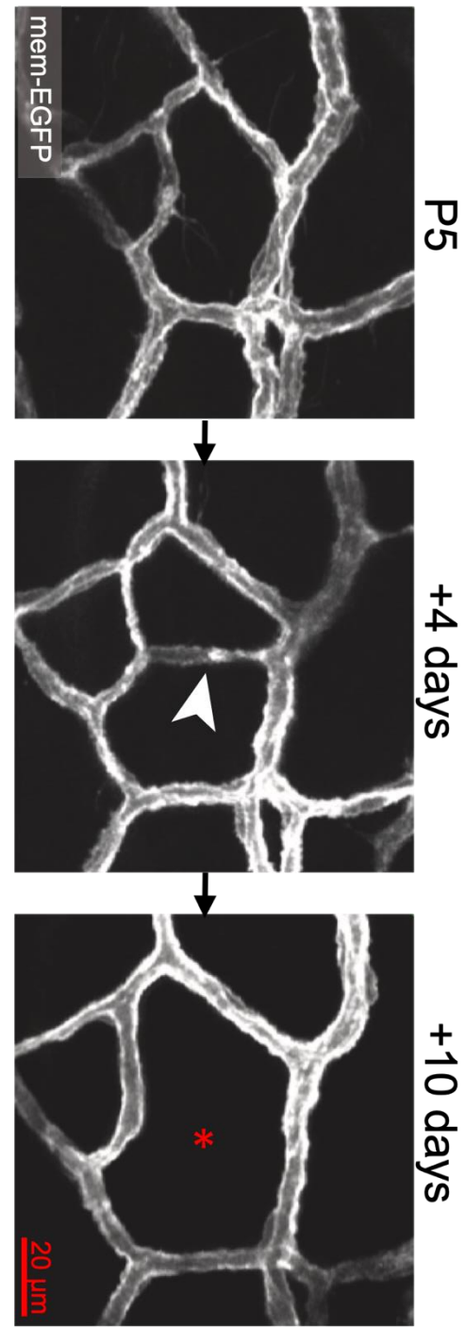
Branching + growth



Permanent growth after hypoxia

Harb, et al., *JCBFM* **33**, 146 (2013)

Skin of baby mice

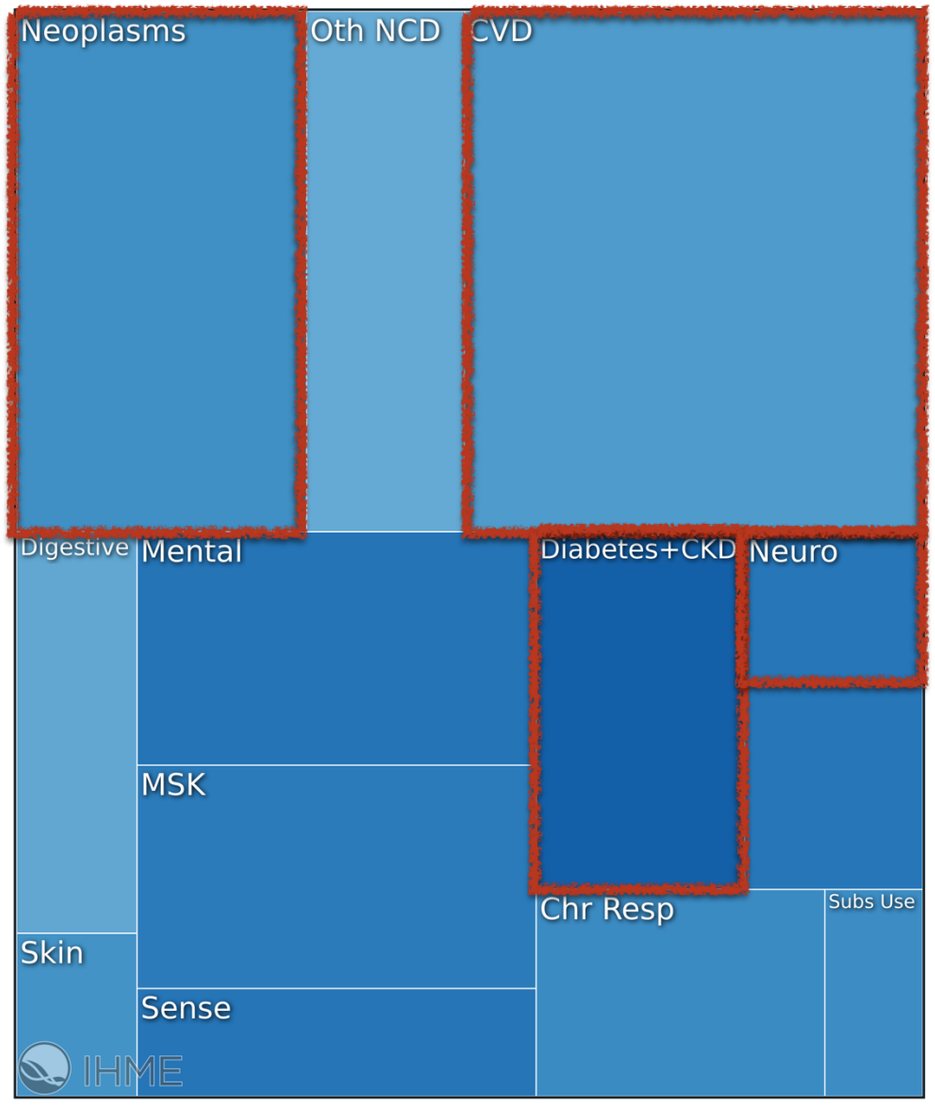


Grow, test, regress

Kam, et al., *Cell* **186**, 2435 (2023)

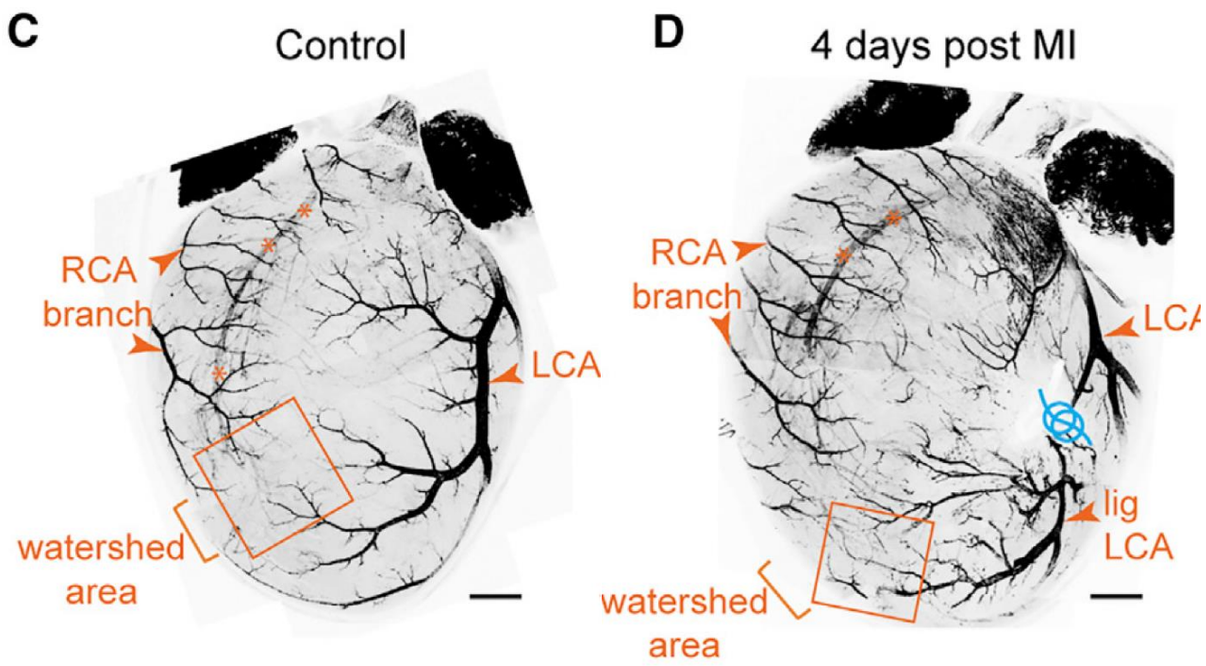
Aiding vascular remodeling is key to many diseases

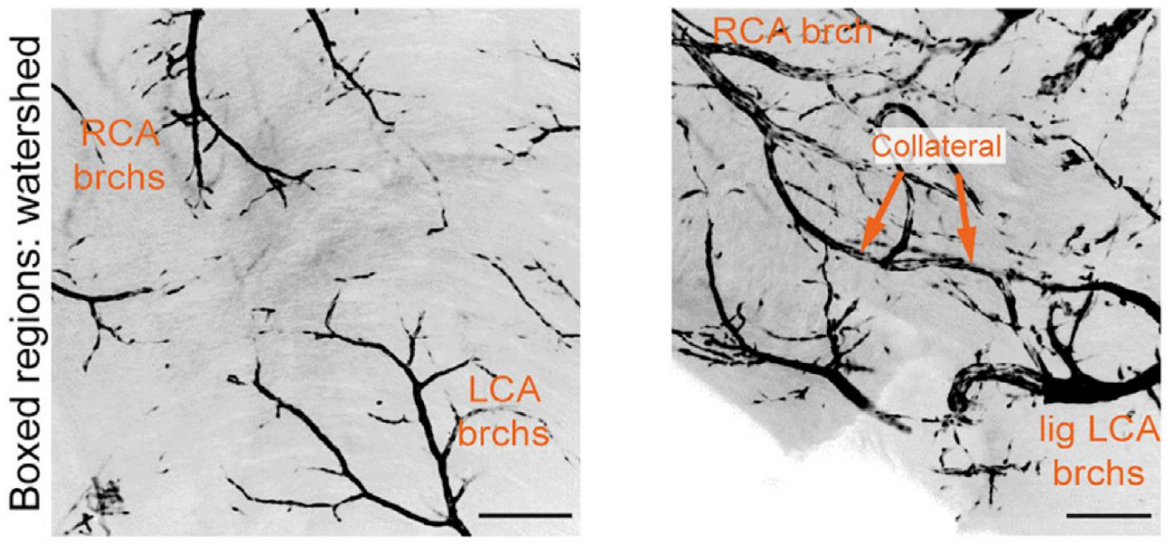
- Stroke
- Cardiovascular disease
- Dementia
- Diabetes
- Cancer



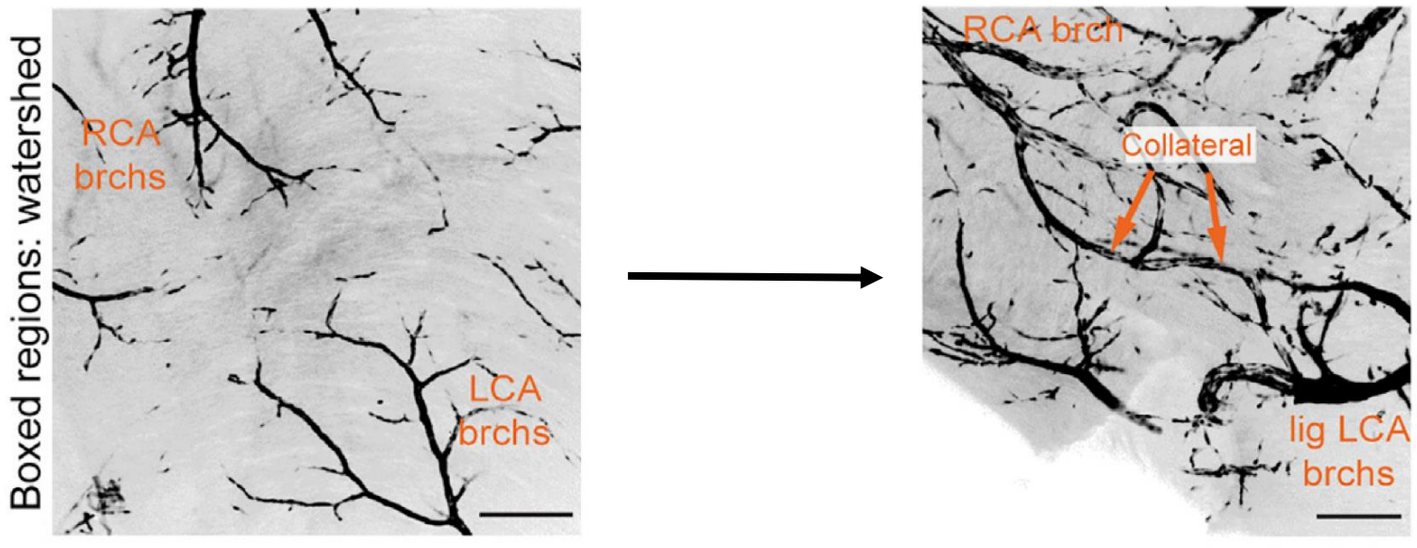
IHME Global Burden of Disease
vizhub.healthdata.org/gbd-compare/

Baby mouse (heart attack)





How to understand and aid vascular recovery?



1-4 day old mice

What prevents this?

- Diabetes
- Hypertension
- Genetics
- Immunodeficiency
- Aging (>1 week in mice!)

What are failure points?

- Redistribute blood flow
- Recruit existing collaterals
- Expanding capillaries into arteries
- Growing new capillaries
- Immune recruitment/inflammatory signaling

Many clinical trial failures: no known drugs to restore vascular structure

New technology to solve spatiotemporal tradeoff in vascular imaging

Smaller structures longitudinally ⟷ Large structures at one time

tradeoff



Two-photon microscopy



Whole mount or serial sectioning

Can we track individual microvessels across whole organs?
Yes: super-resolution ultrasound

Ji, et al., *PNAS* **123**, e2521872123 (2026)

Kirst, et al., *Cell* **180**, P780 (2020)

Quick aside: how does ultrasound imaging work?

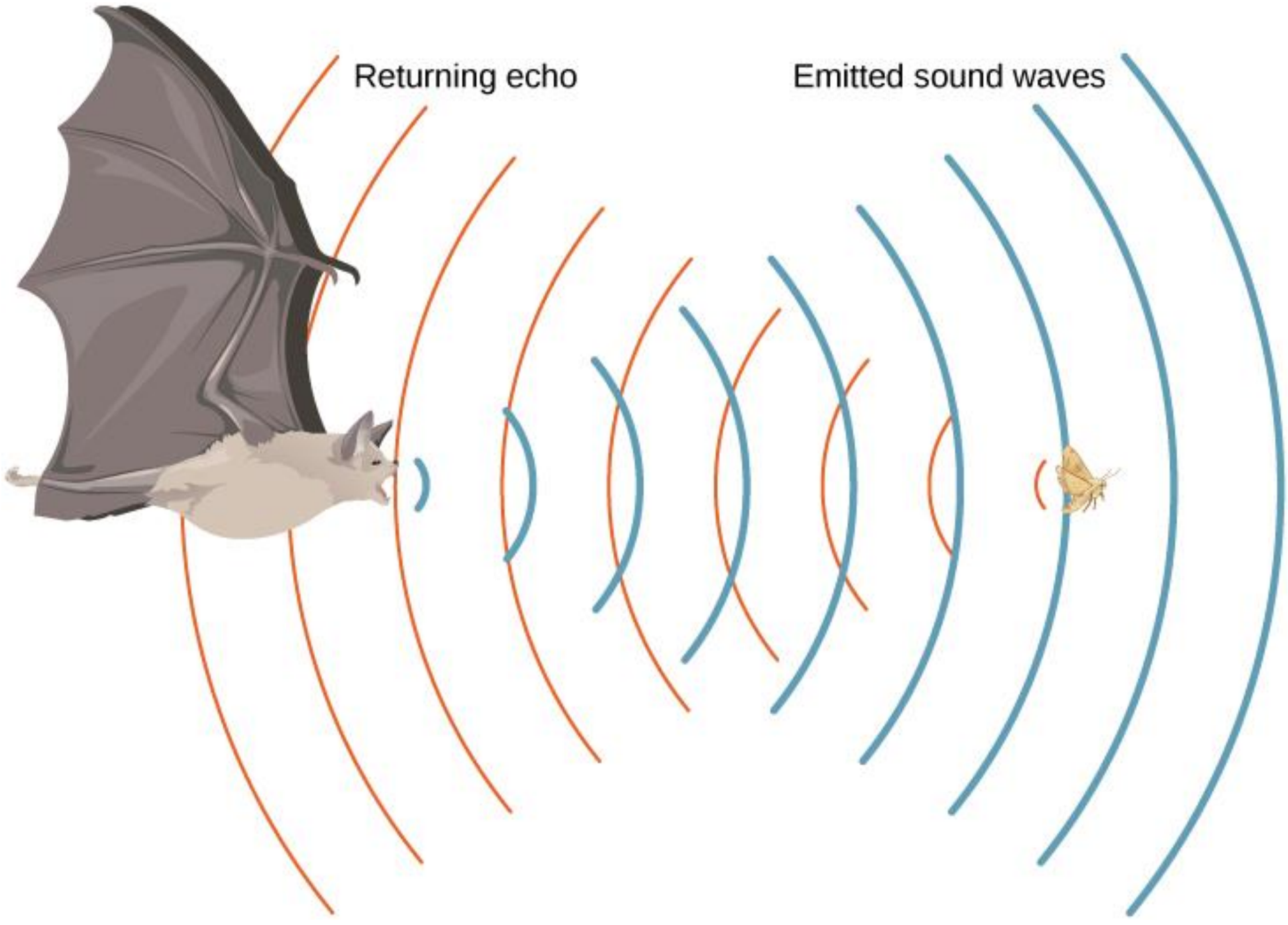


Image: OpenStax, University Physics Vol. 1, Ch. 17, via Wikimedia Commons. CC BY 4.0.

Quick aside: how does ultrasound imaging work?

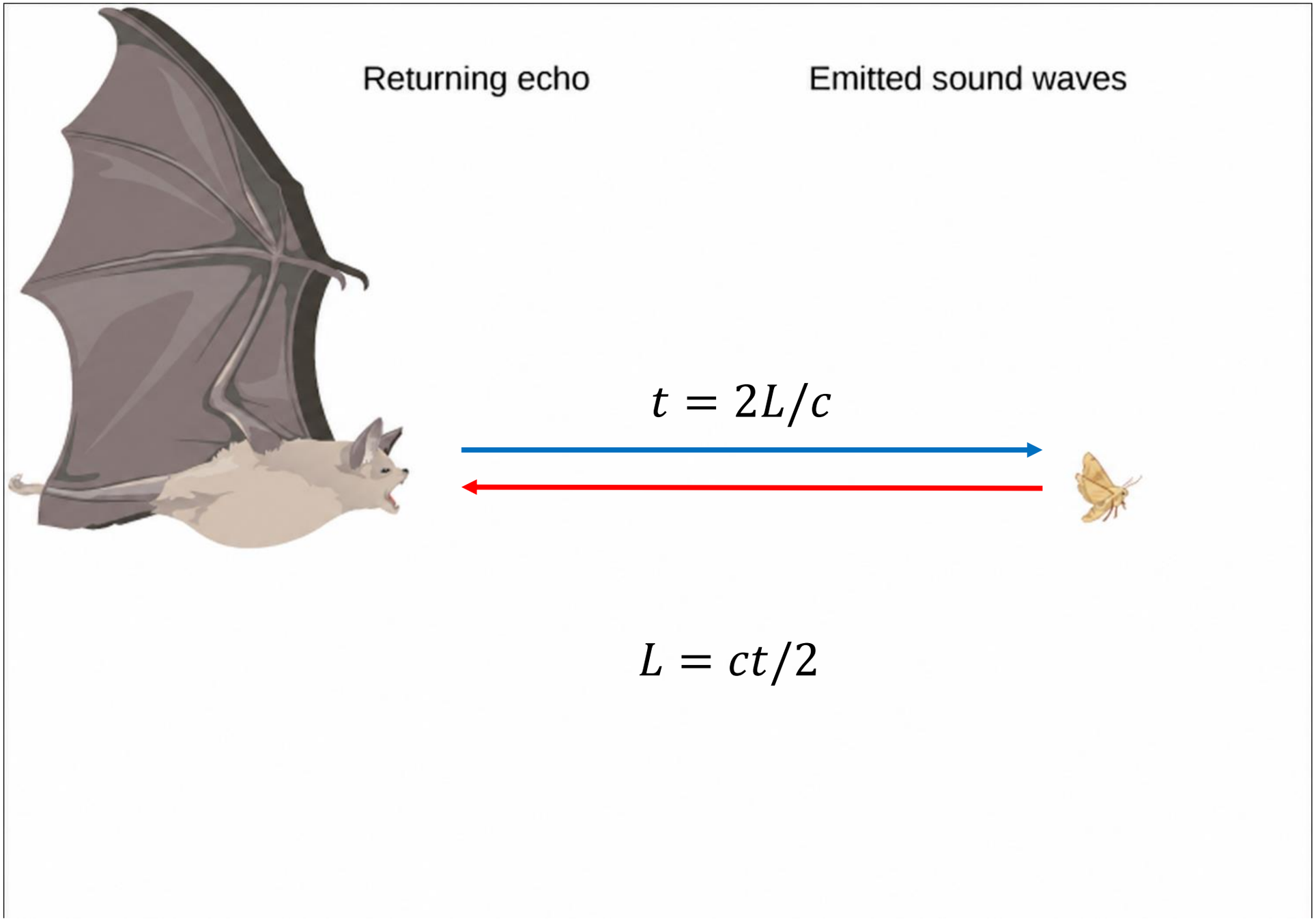


Image: OpenStax, University Physics Vol. 1, Ch. 17, via Wikimedia Commons. CC BY 4.0.

How to turn this into an image?

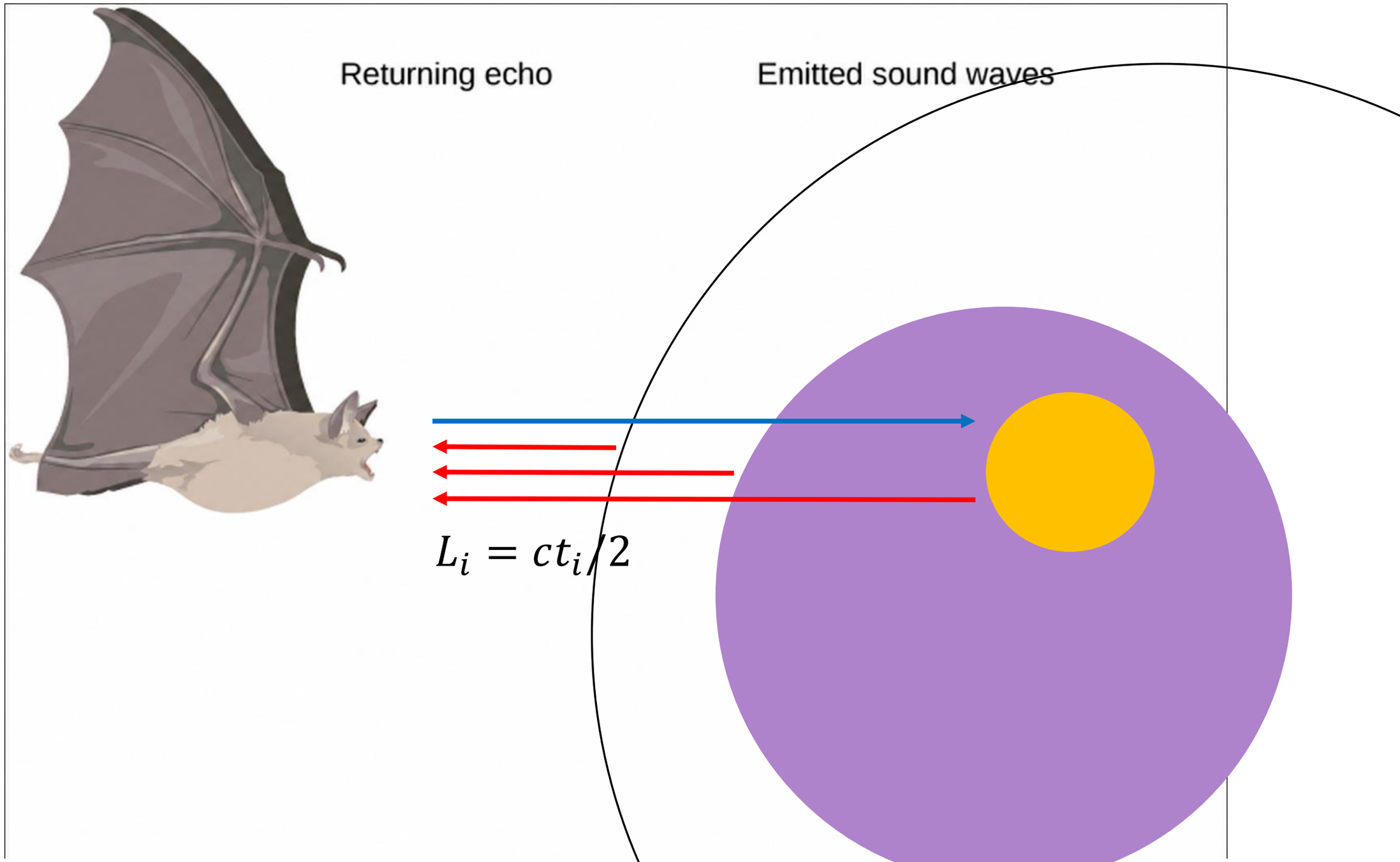
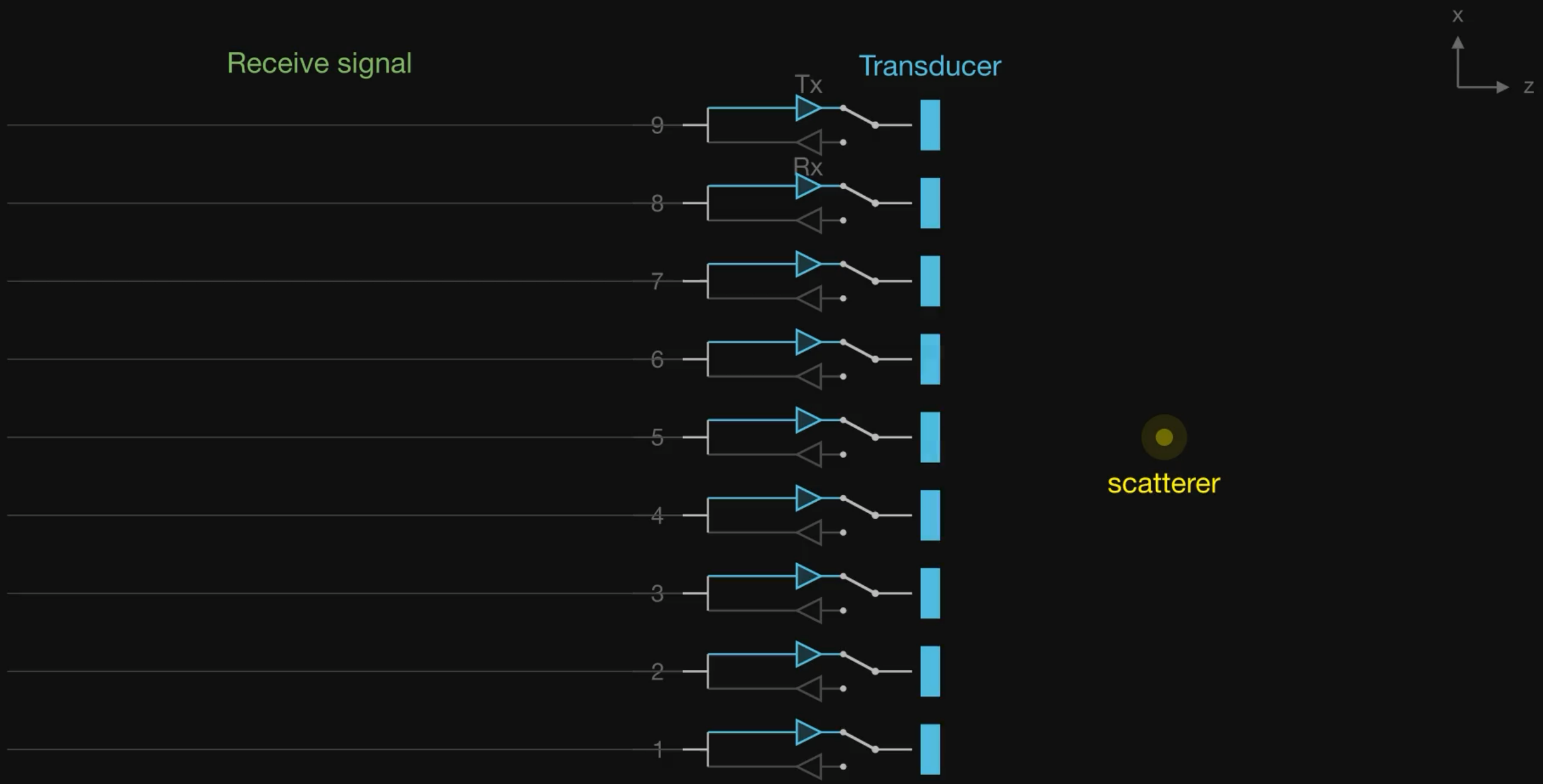
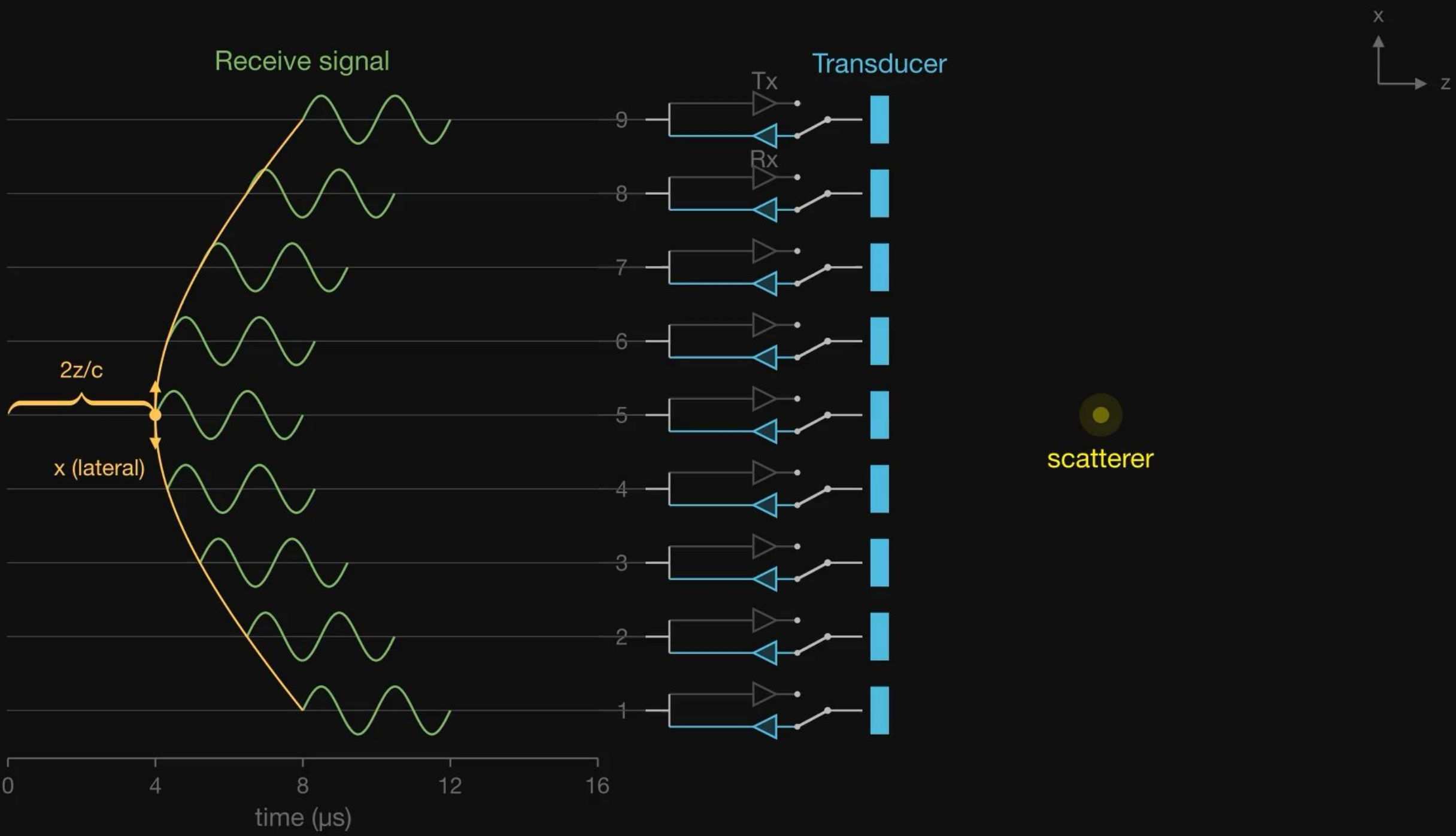


Image: OpenStax, University Physics Vol. 1, Ch. 17, via Wikimedia Commons. CC BY 4.0.

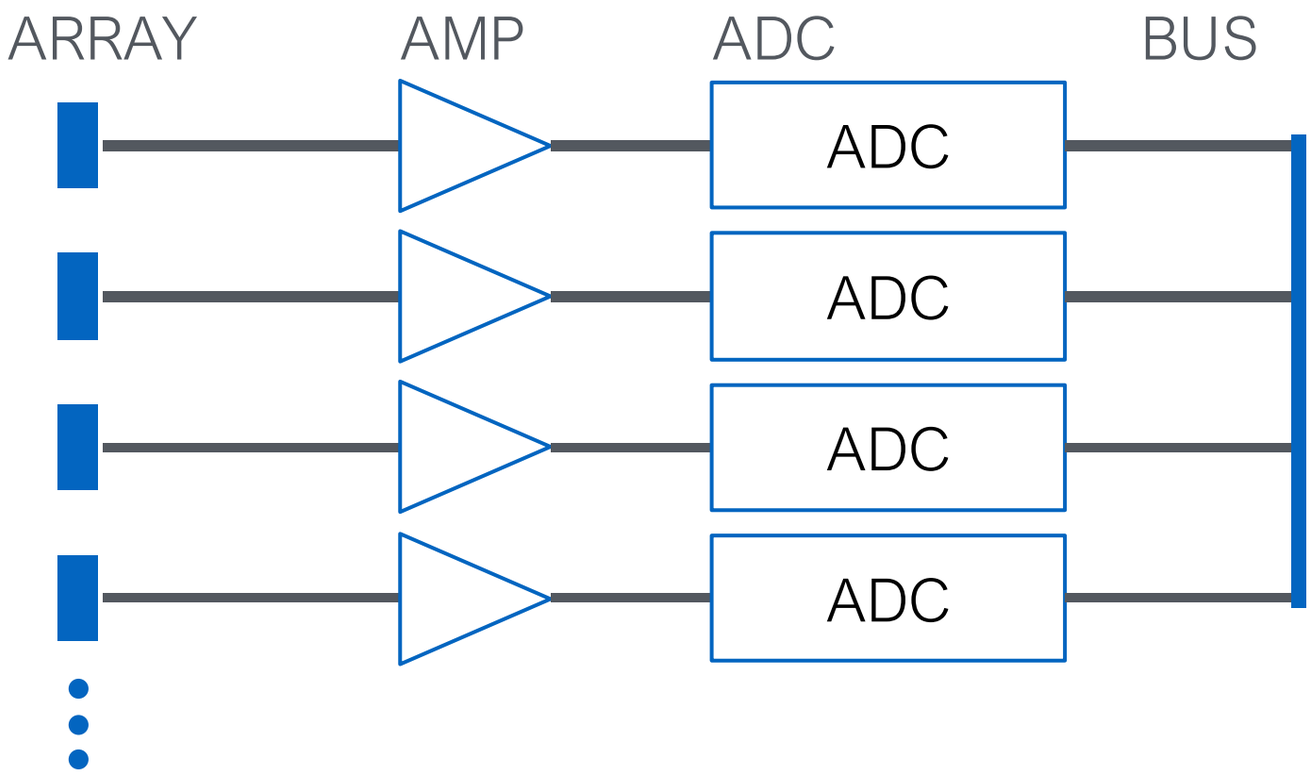


Thank you, Claude code! Programmed with manim, same toolbox at 3blue1brown



Thank you, Claude code! Programmed with manim, same toolbox at 3blue1brown

Ultrasound natively generates enormous data rates



20 GB/s

peak

×250 channels

40 MS/s · 16 bit



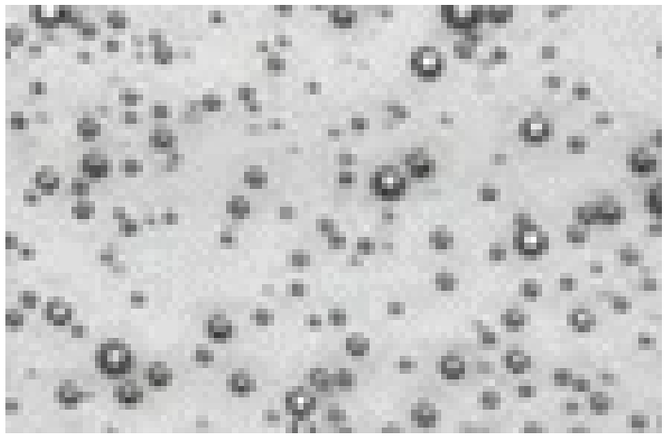
7 MB

per image

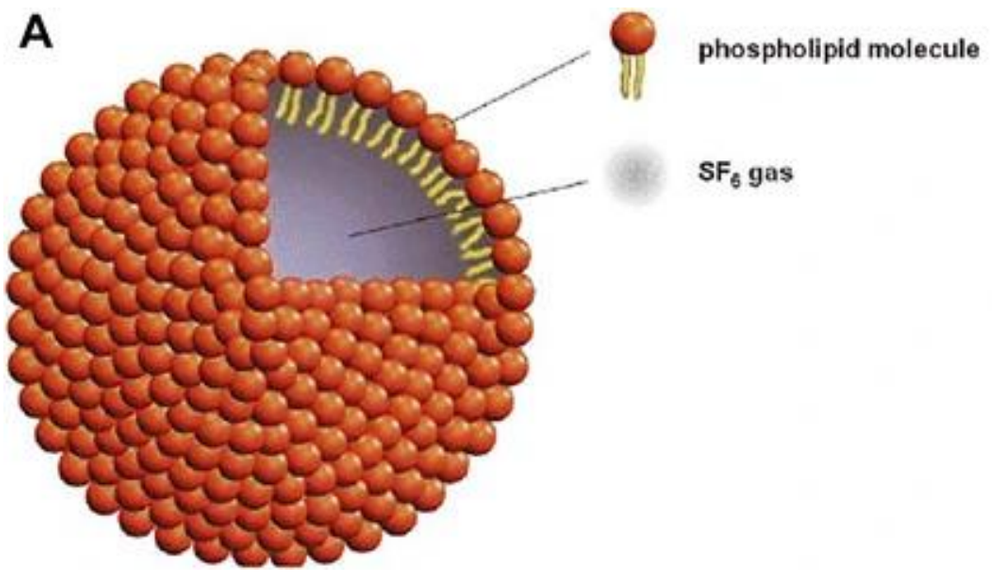
5 angles × 70 µs = one image

My lab: 1000 images per second = 6 GB/s sustained

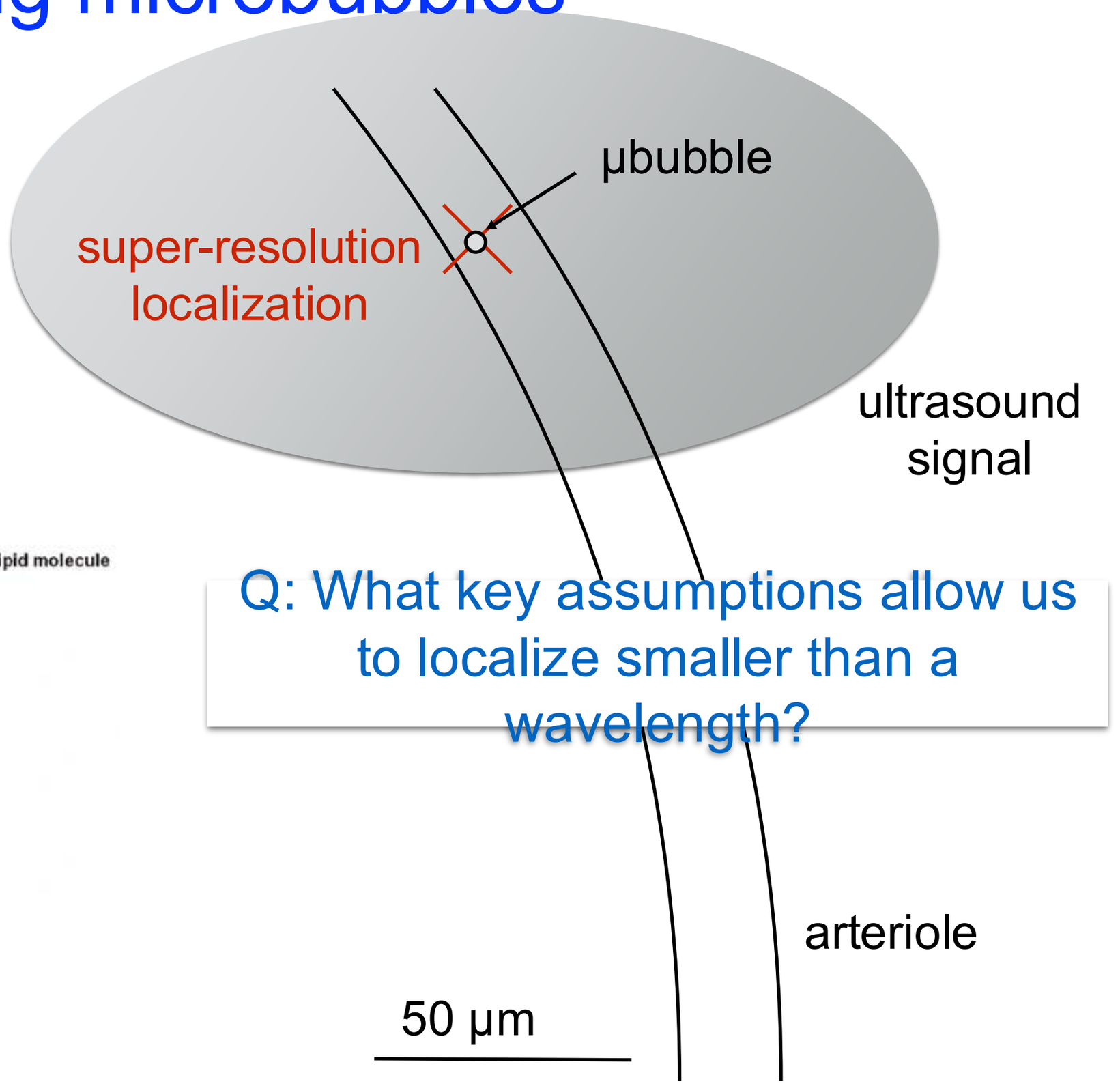
Super-resolution ultrasound works by localizing moving microbubbles



FDA approved contrast agents

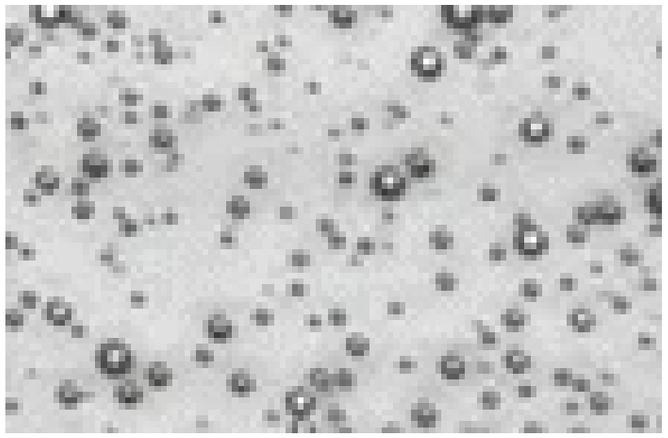


Chong, *et al.*, *Abdominal Radiology* **43**, 762 (2018)

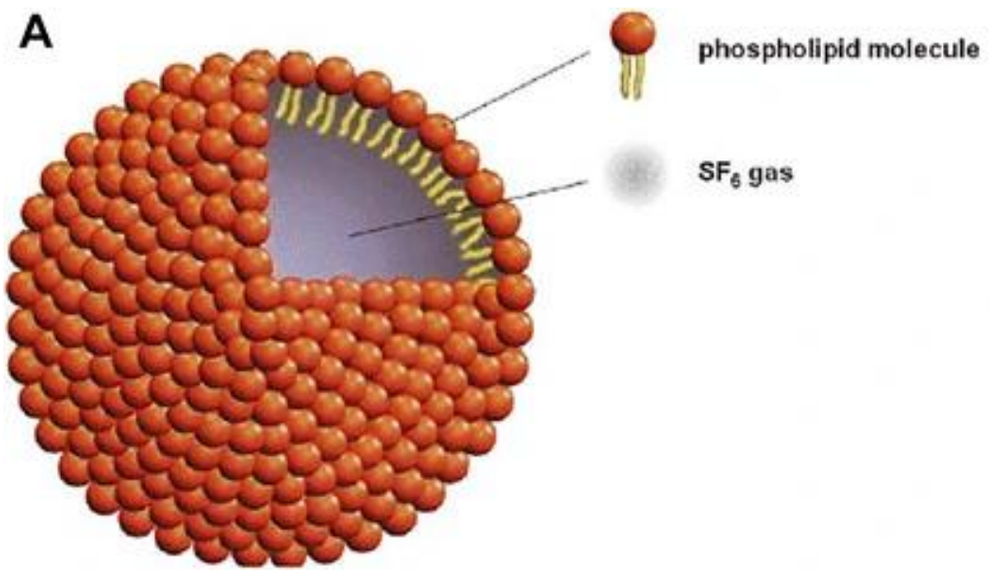


Q: What key assumptions allow us to localize smaller than a wavelength?

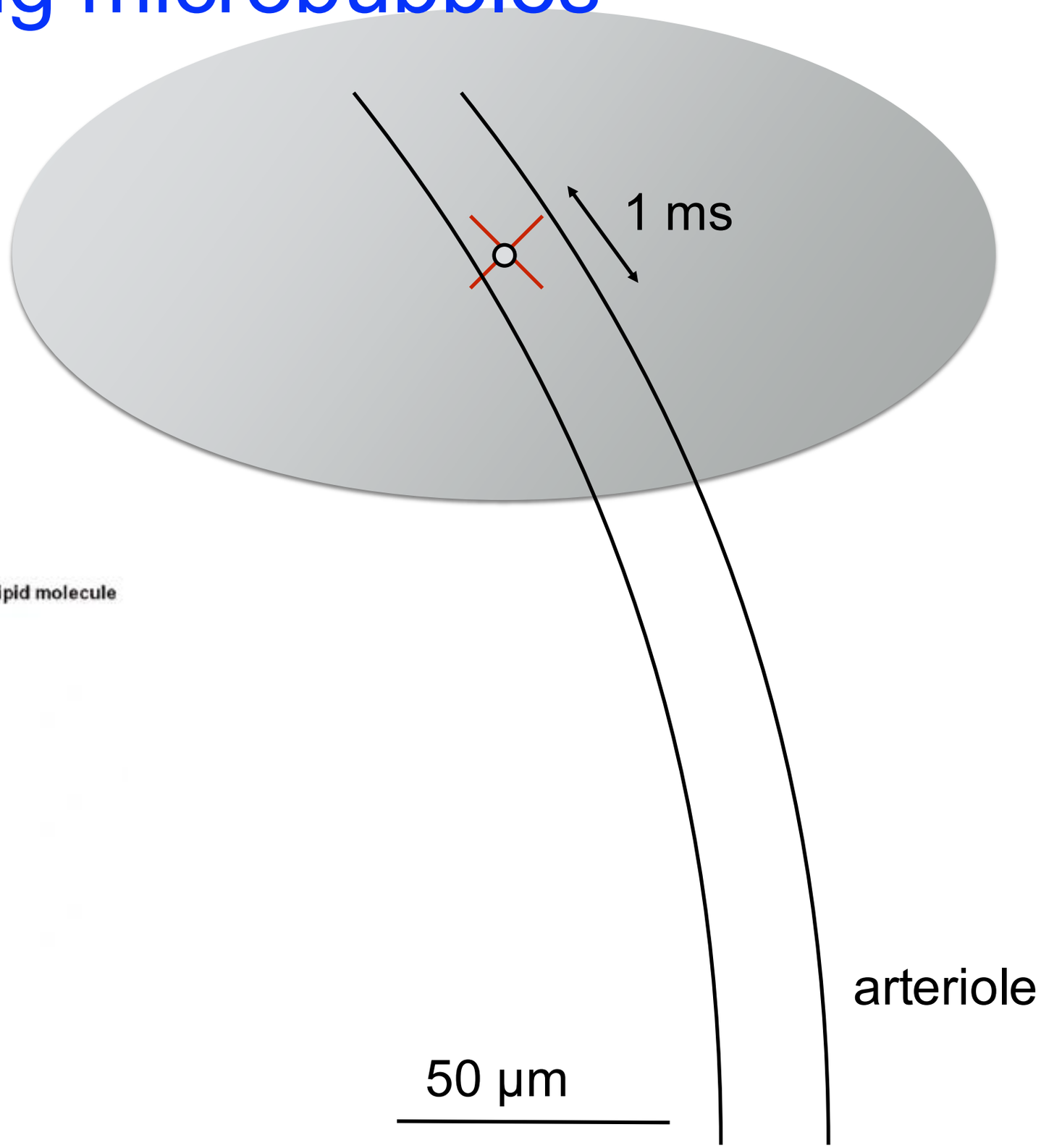
Super-resolution ultrasound works by localizing moving microbubbles



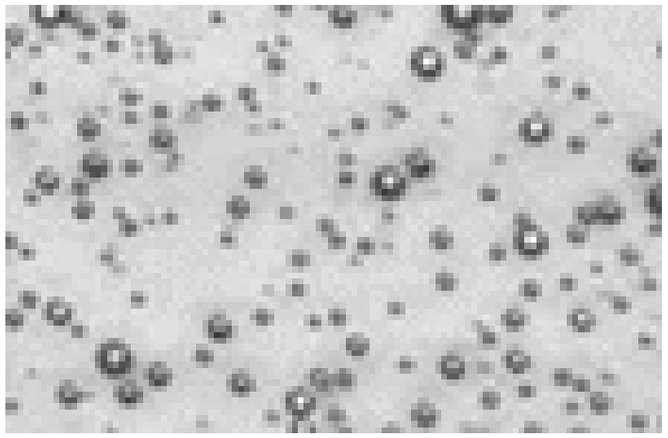
FDA approved contrast agents



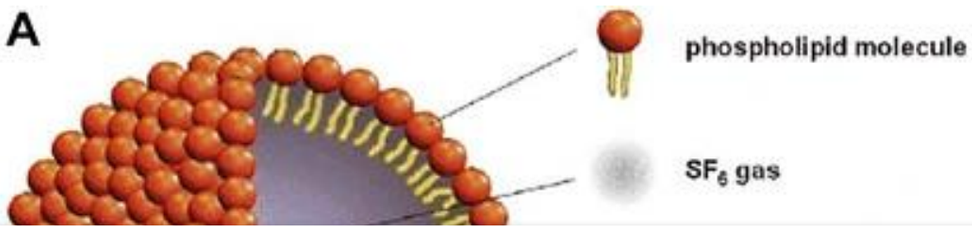
Chong, *et al.*, *Abdominal Radiology* **43**, 762 (2018)



Super-resolution ultrasound works by localizing moving microbubbles



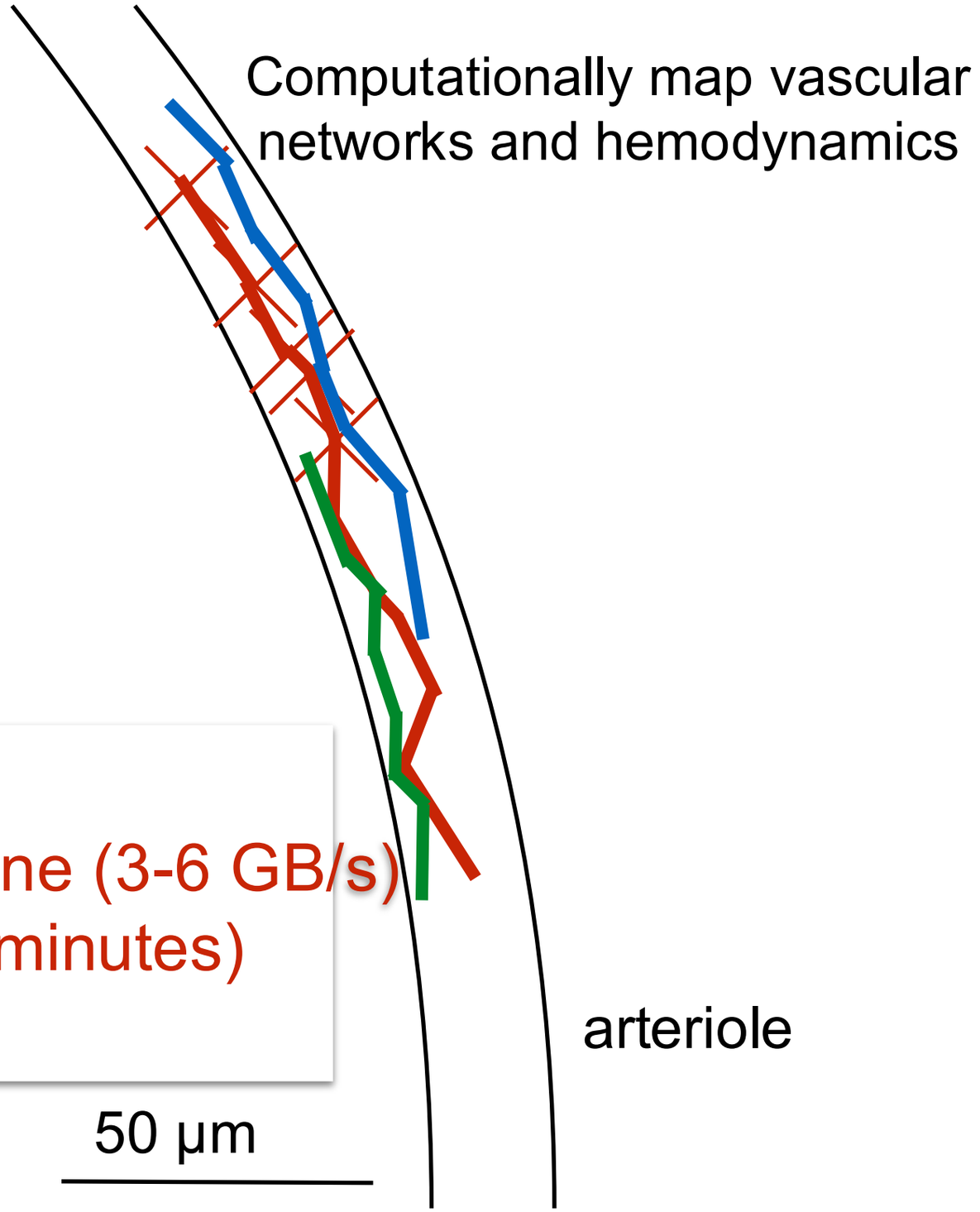
FDA approved contrast agents



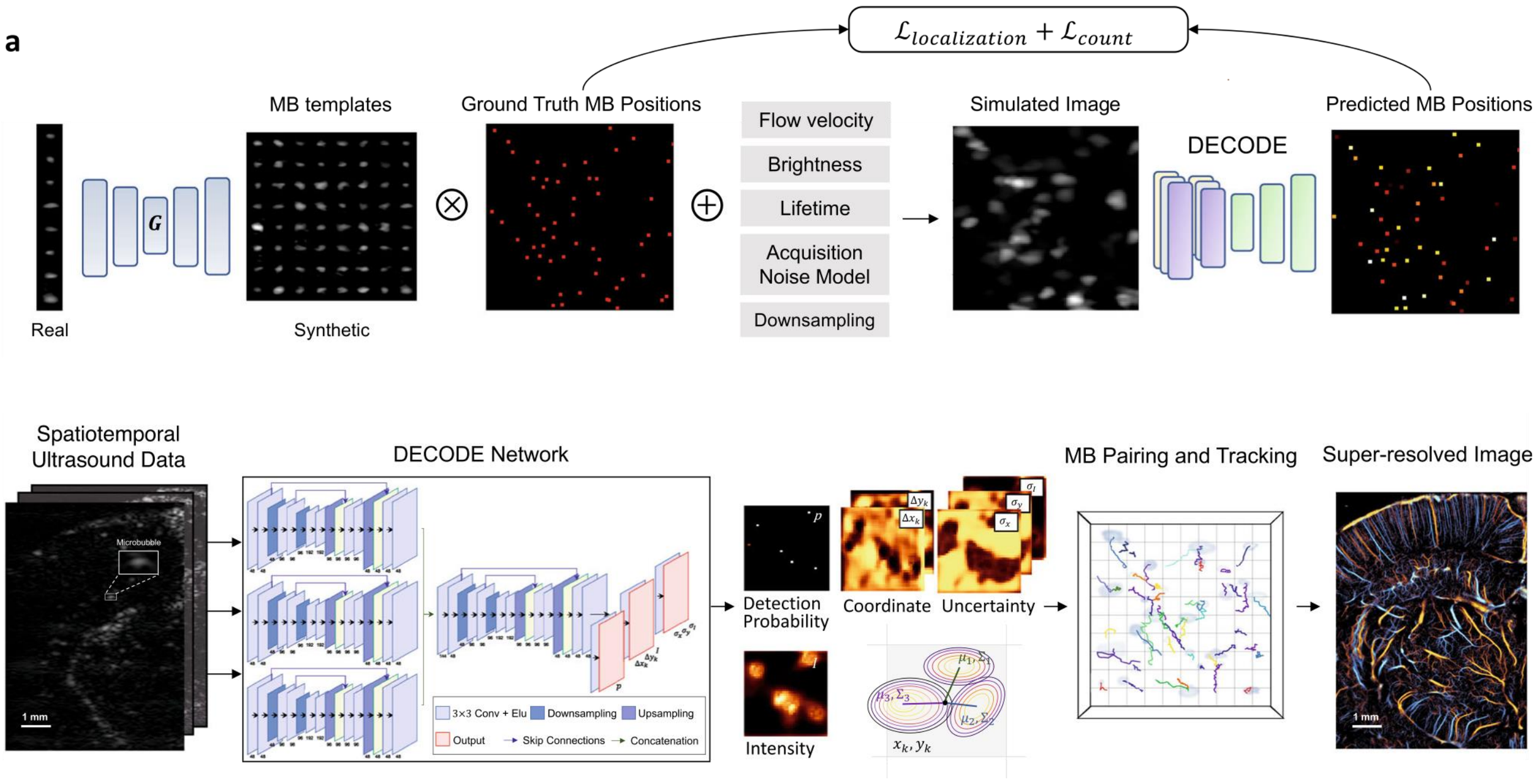
Requires:

- High-frame-rate ultrasound machine (3-6 GB/s)
- Extended imaging sessions (>10 minutes)
- 6 GB/s x 10 minutes = 3.4 TB

Chong, *et al.*, *Abdominal Radiology* **43**, 762 (2018)

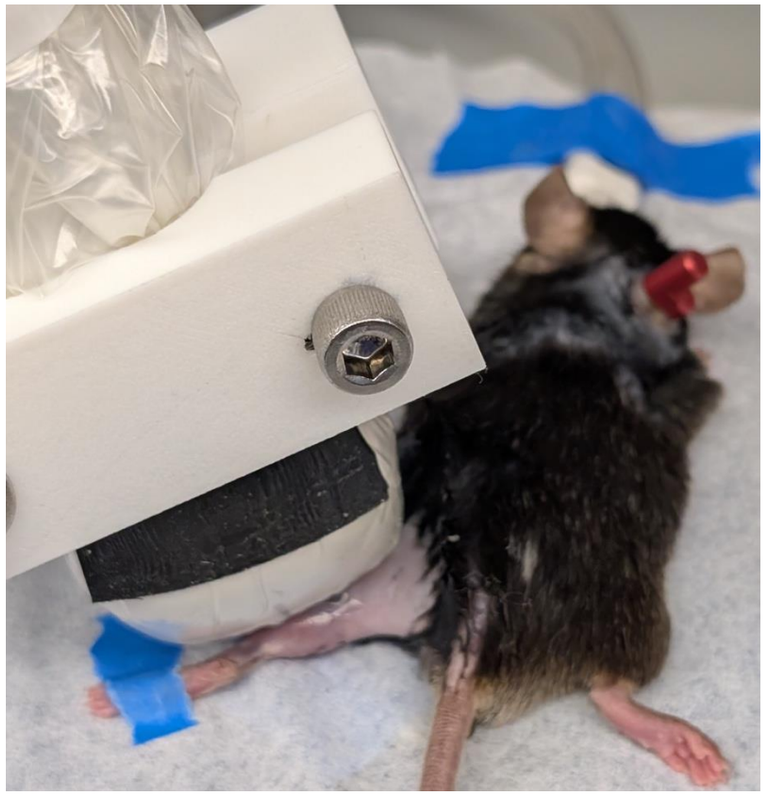


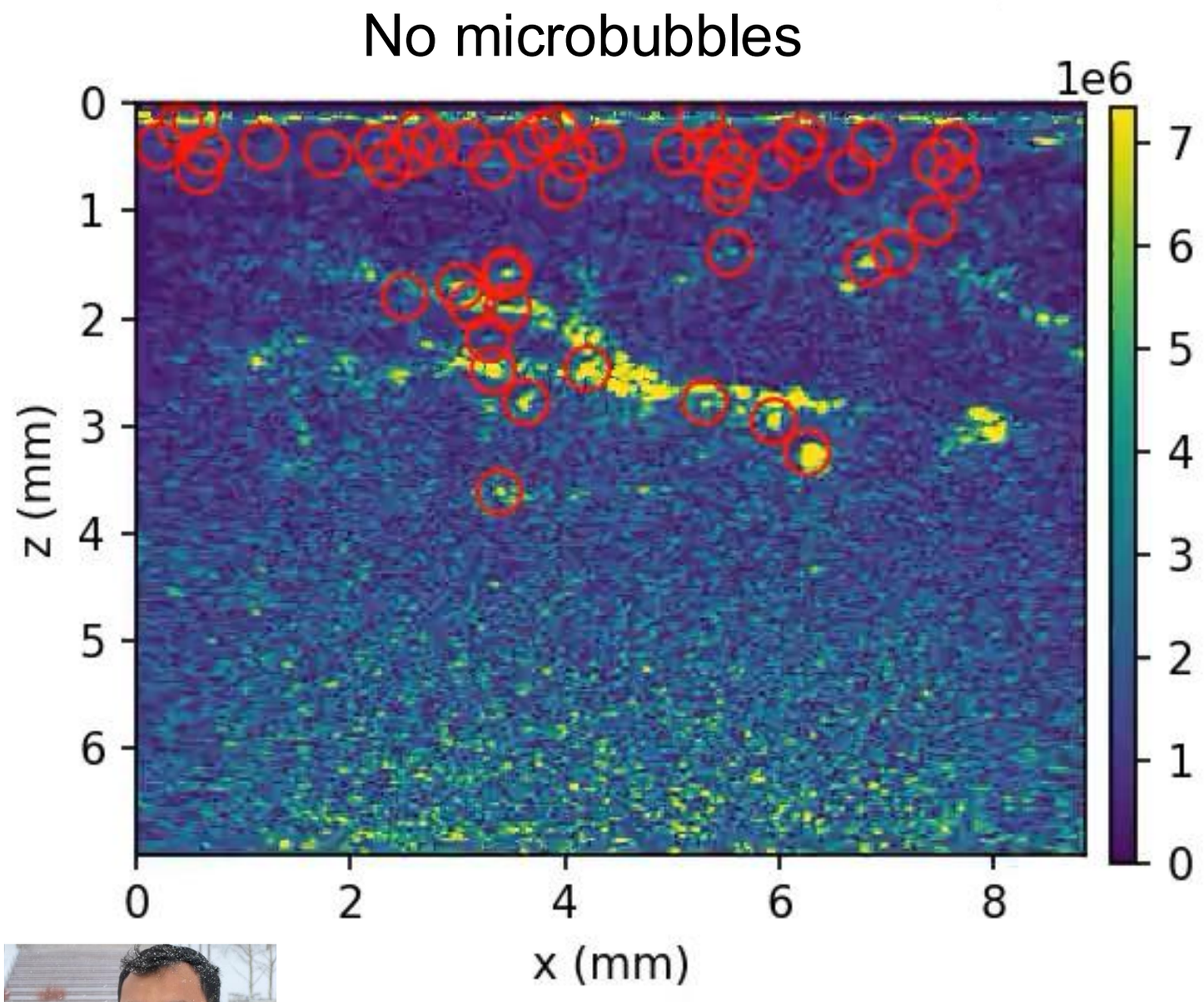
Deep learning-aided microbubble tracking



Shin, et al., *Nature Comm.* **15**, 2932 (2024)

Example: hindlimb imaging in my lab







Dr. El Houcine El Fatimi

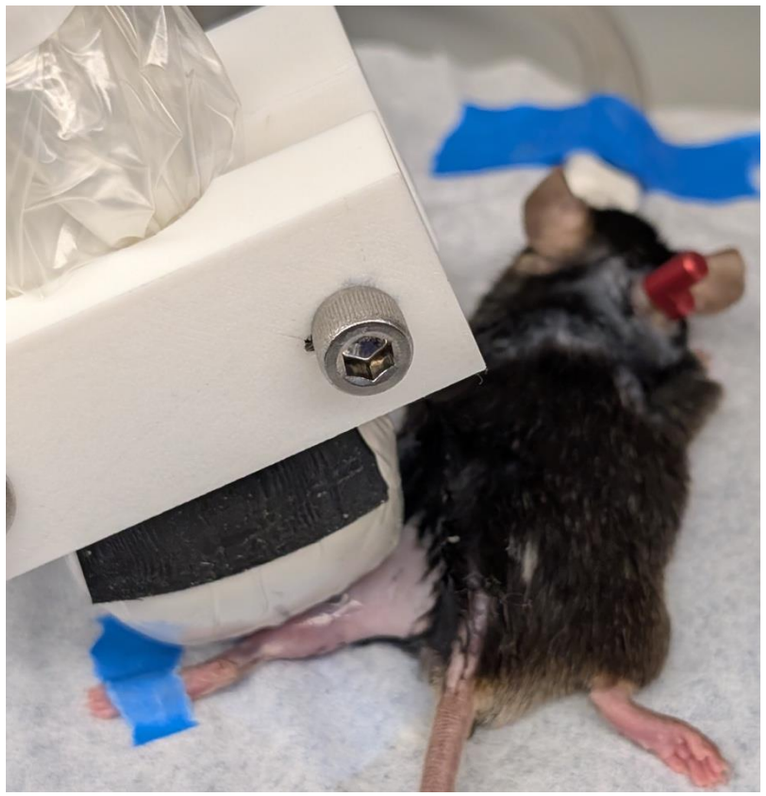


Dr. Kaustubh Naik

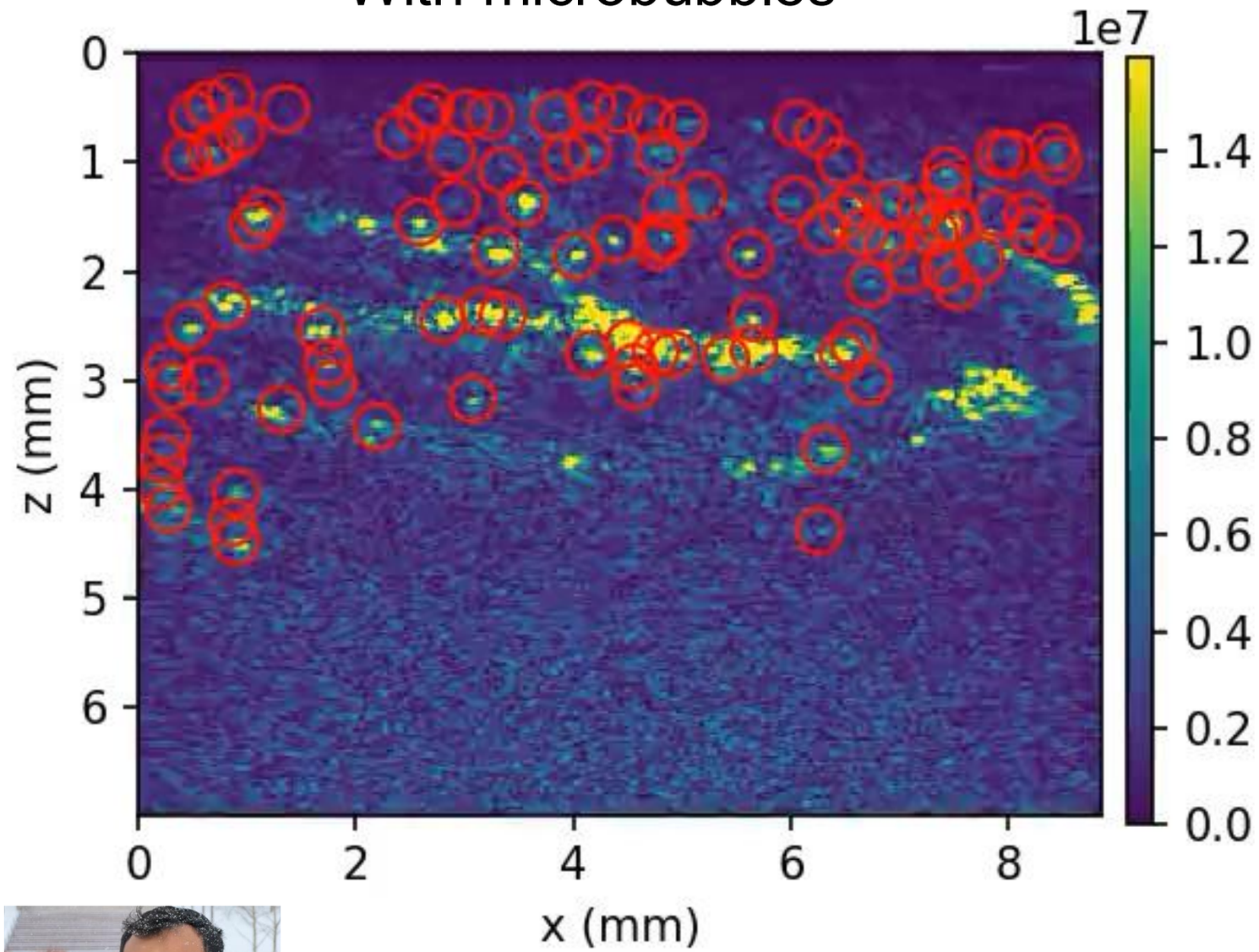


Maruf Hossain

Example: hindlimb imaging in my lab



With microbubbles





Dr. El Houcine El Fatimi

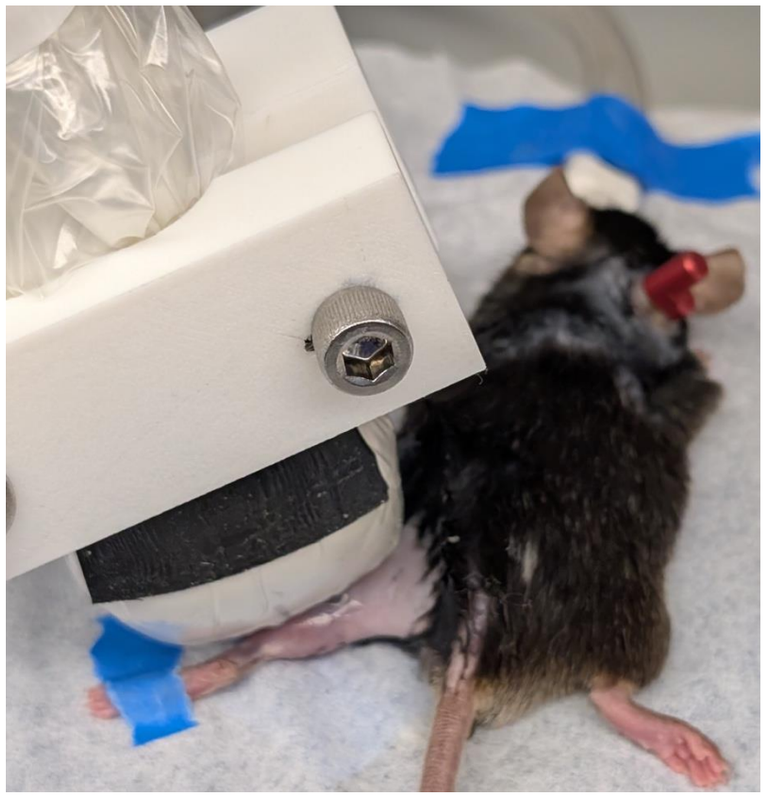


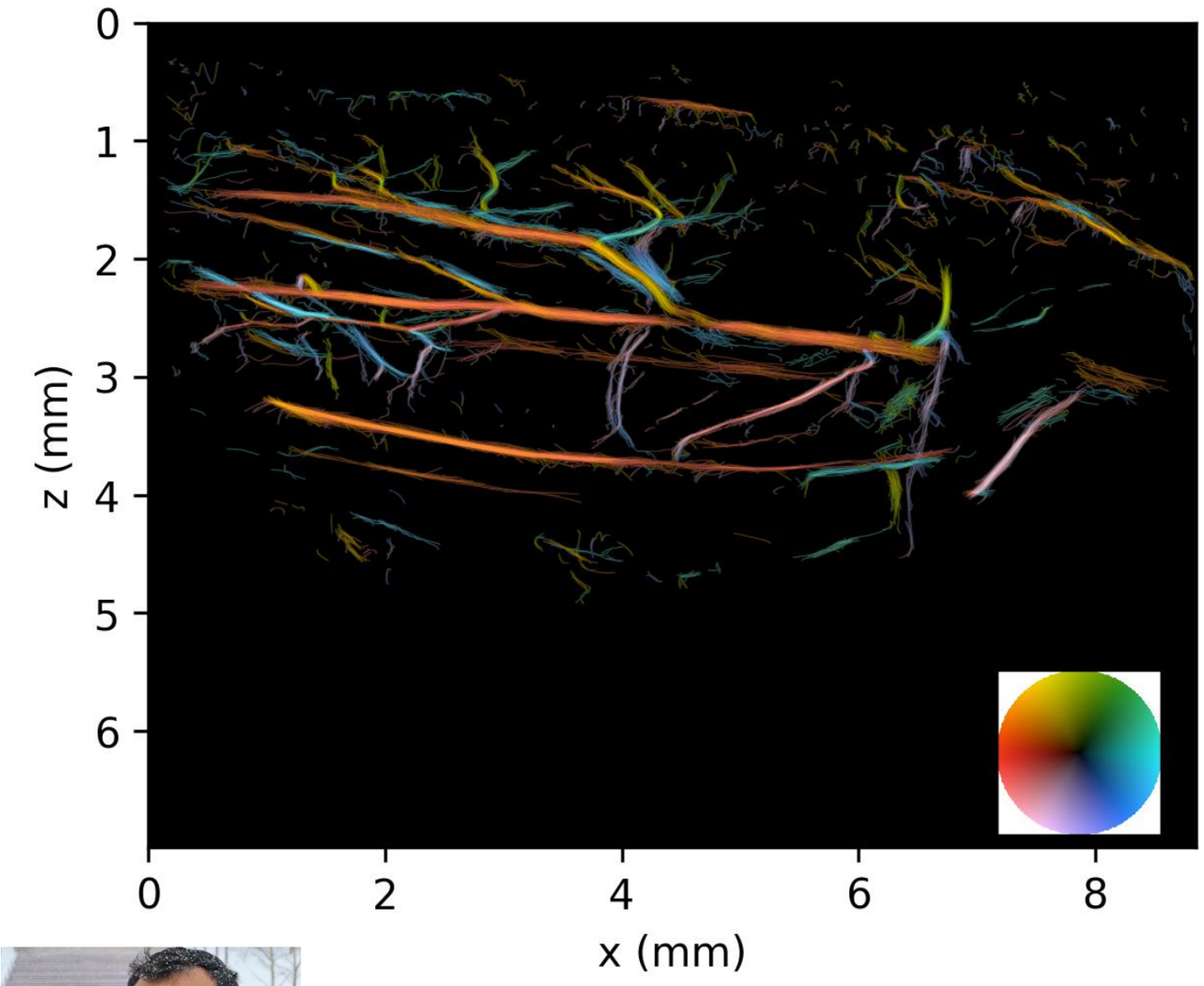
Dr. Kaustubh Naik



Maruf Hossain

Example: hindlimb imaging in my lab







Dr. El Houcine El Fatimi

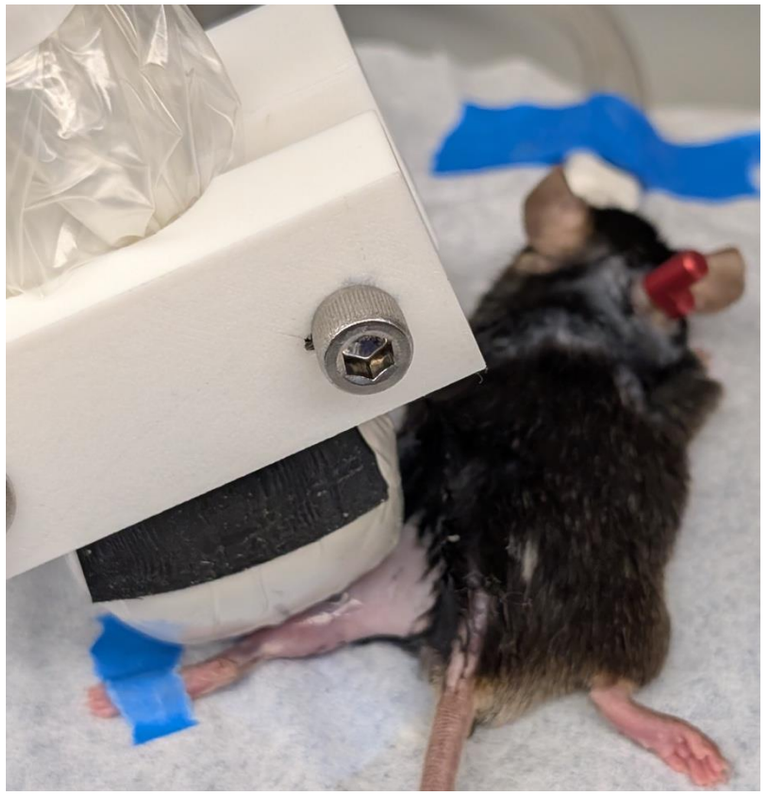


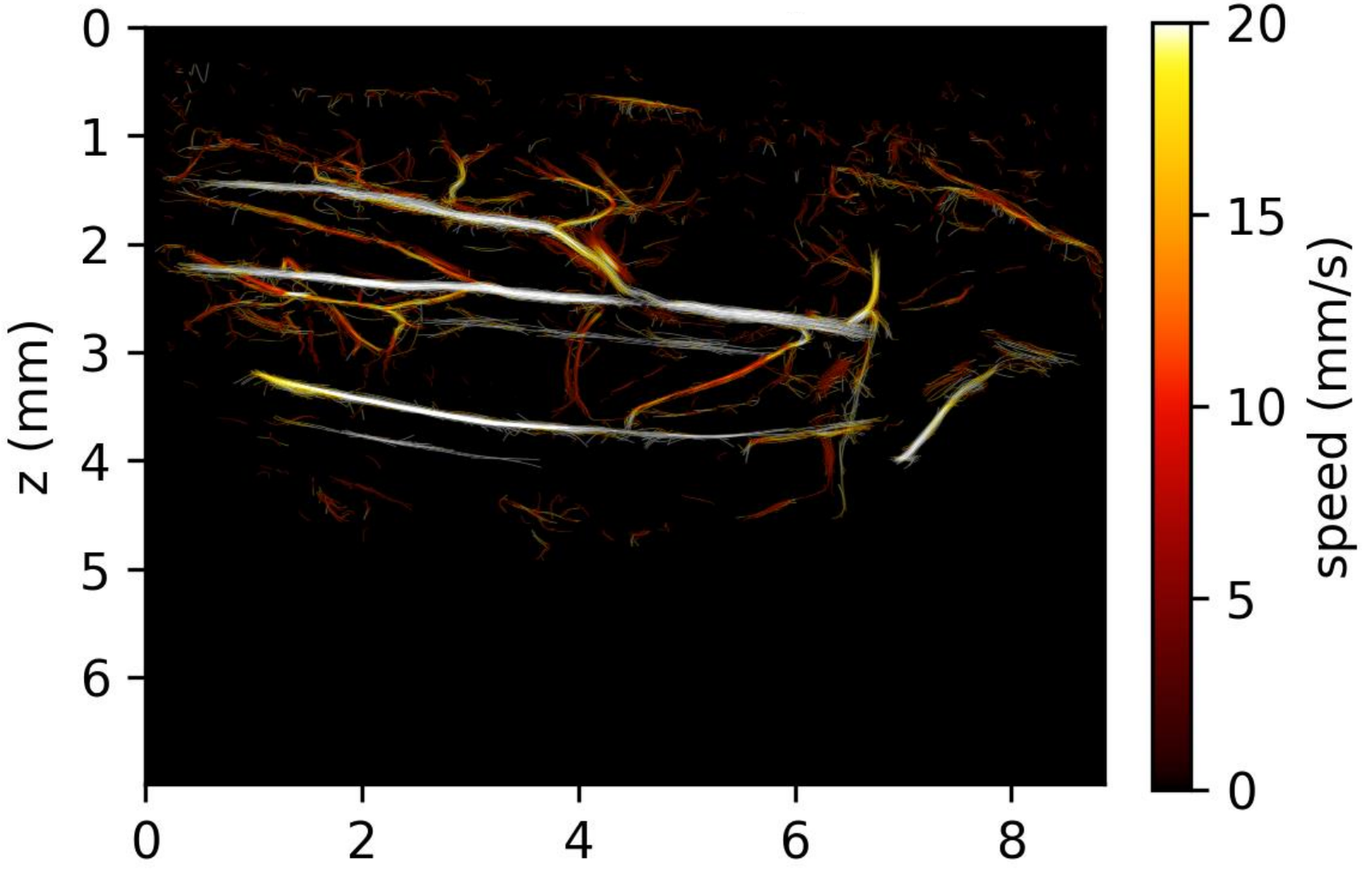
Dr. Kaustubh Naik



Maruf Hossain

Example: hindlimb imaging in my lab







Dr. El Houcine El Fatimi

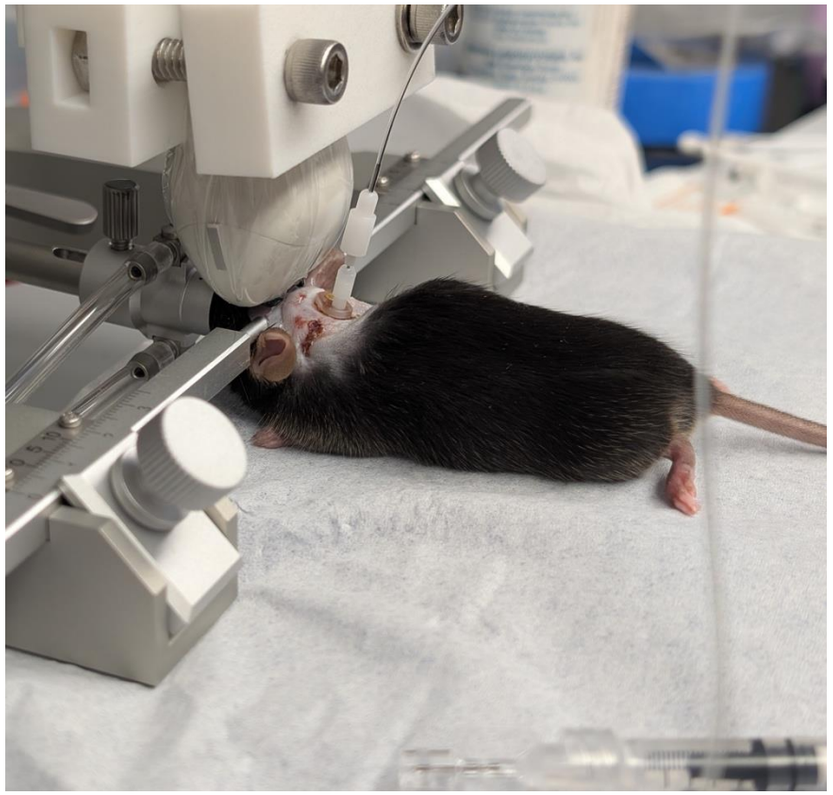


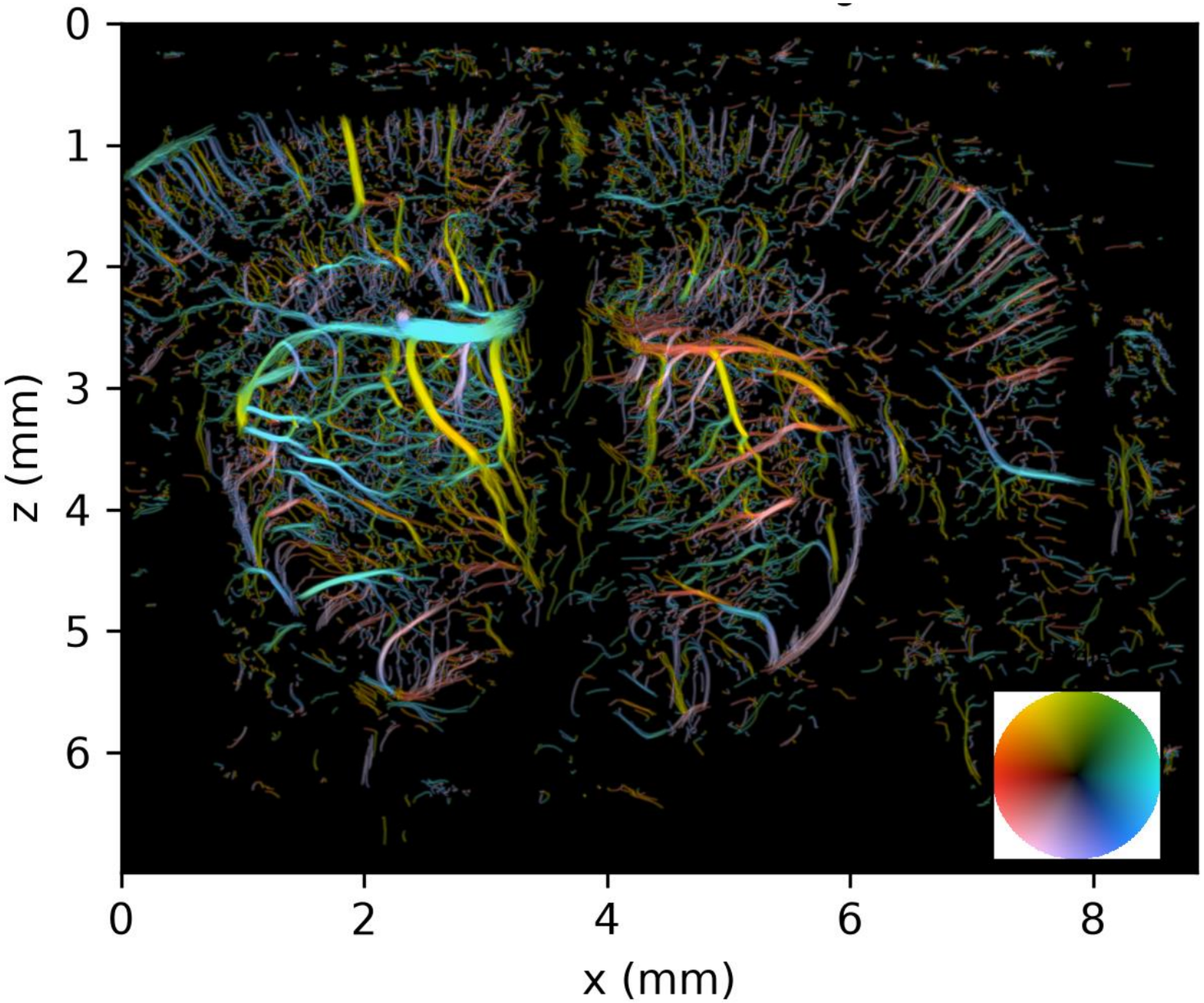
Dr. Kaustubh Naik



Maruf Hossain

Example: cerebrovascular imaging







Dr. El Houcine El Fatimi



Dr. Kaustubh Naik



Maruf Hossain



Dr. Tamy Abou-Antoun

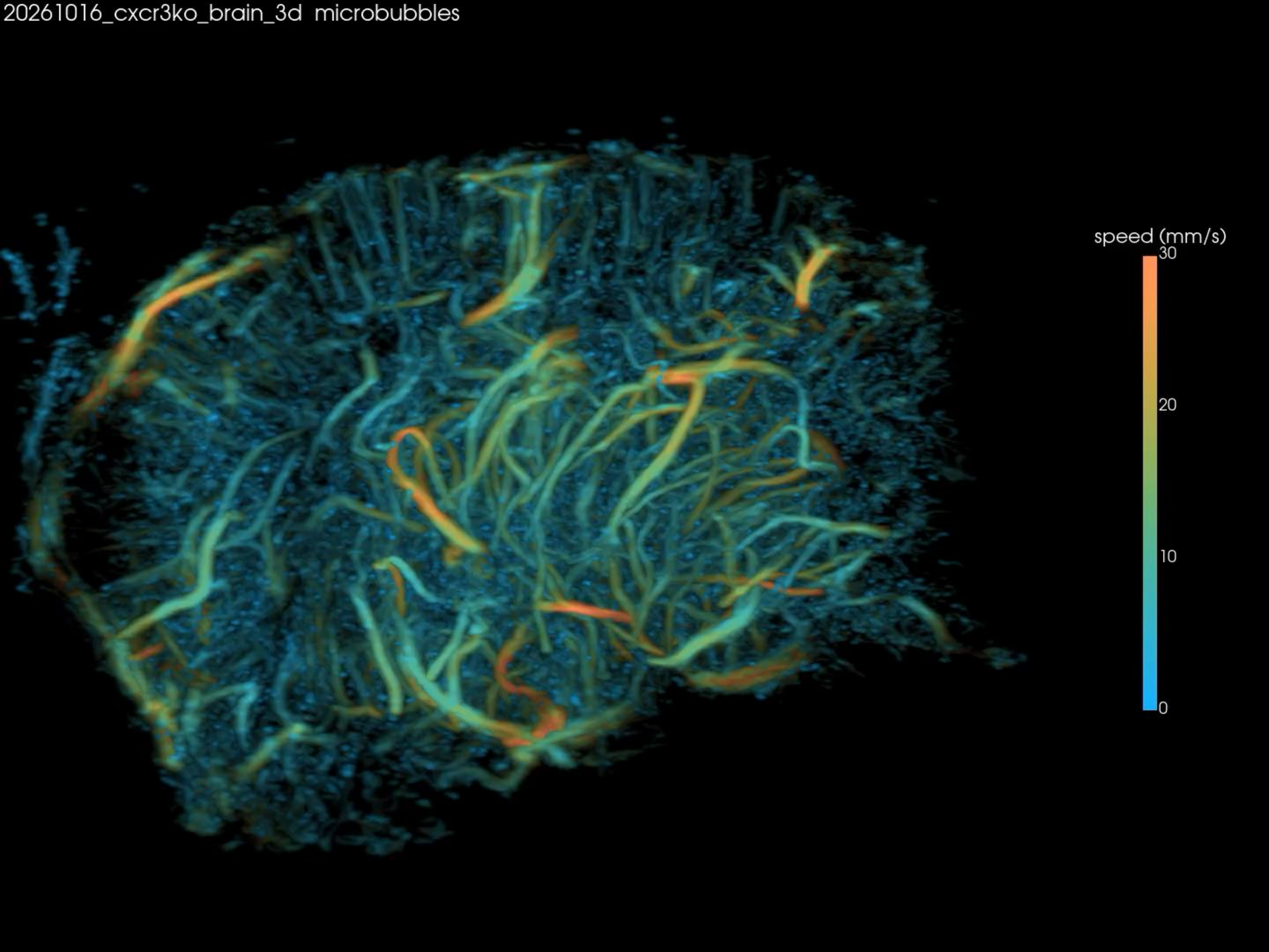


Dr. Ryan Bowen

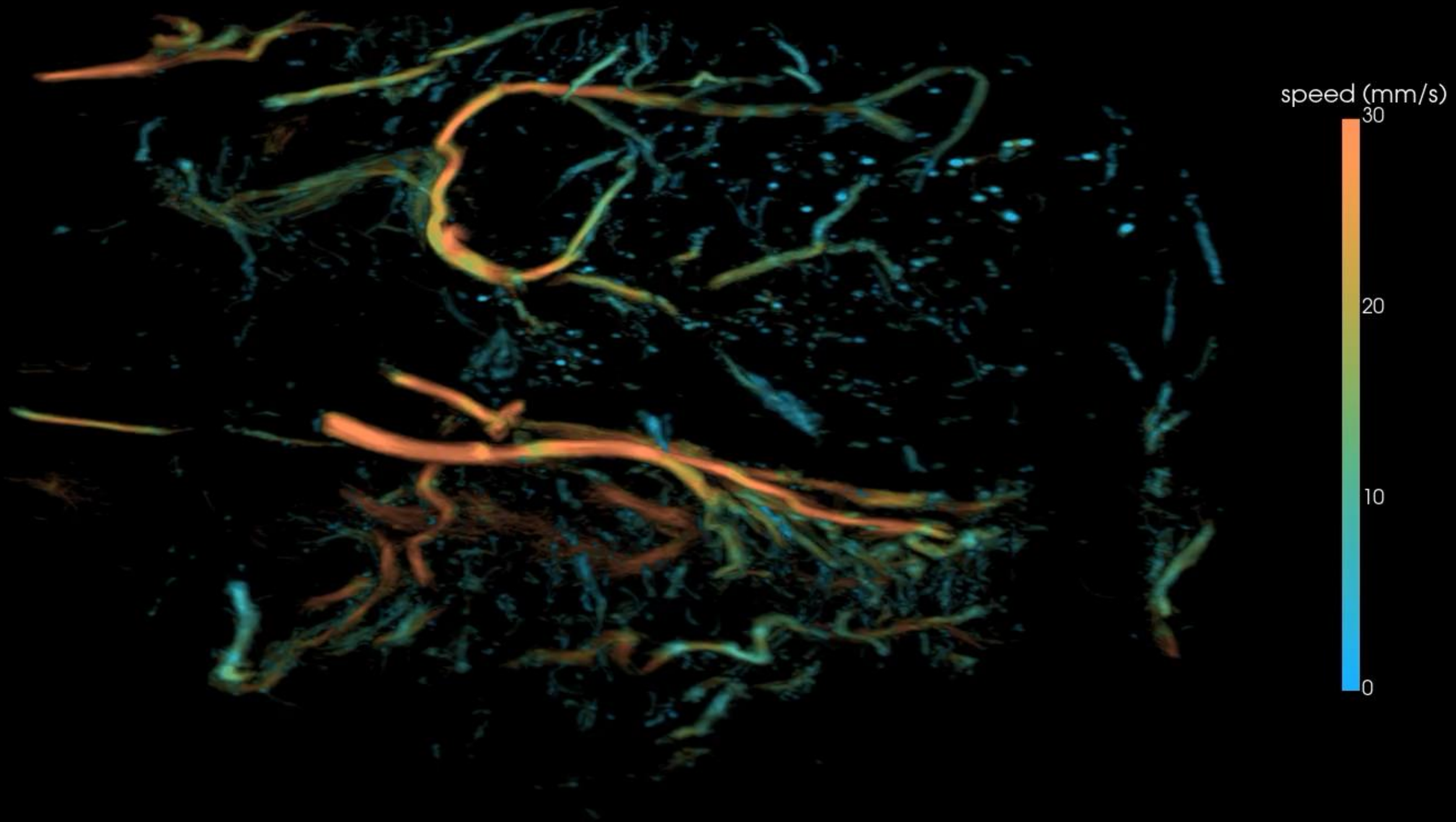
What about 3D?



20261016_cxcr3ko_brain_3d microbubbles



20261020_hindlimb_ischemia_3d ischemia

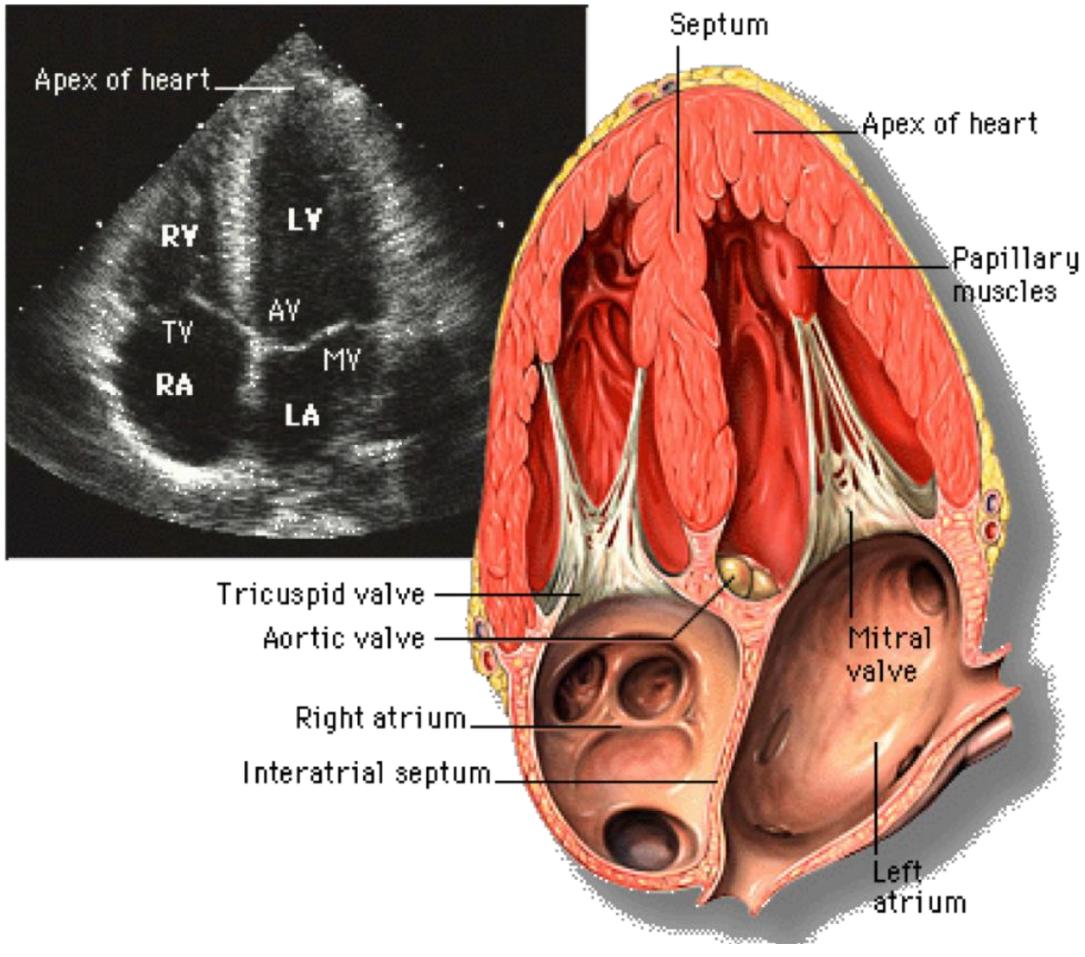


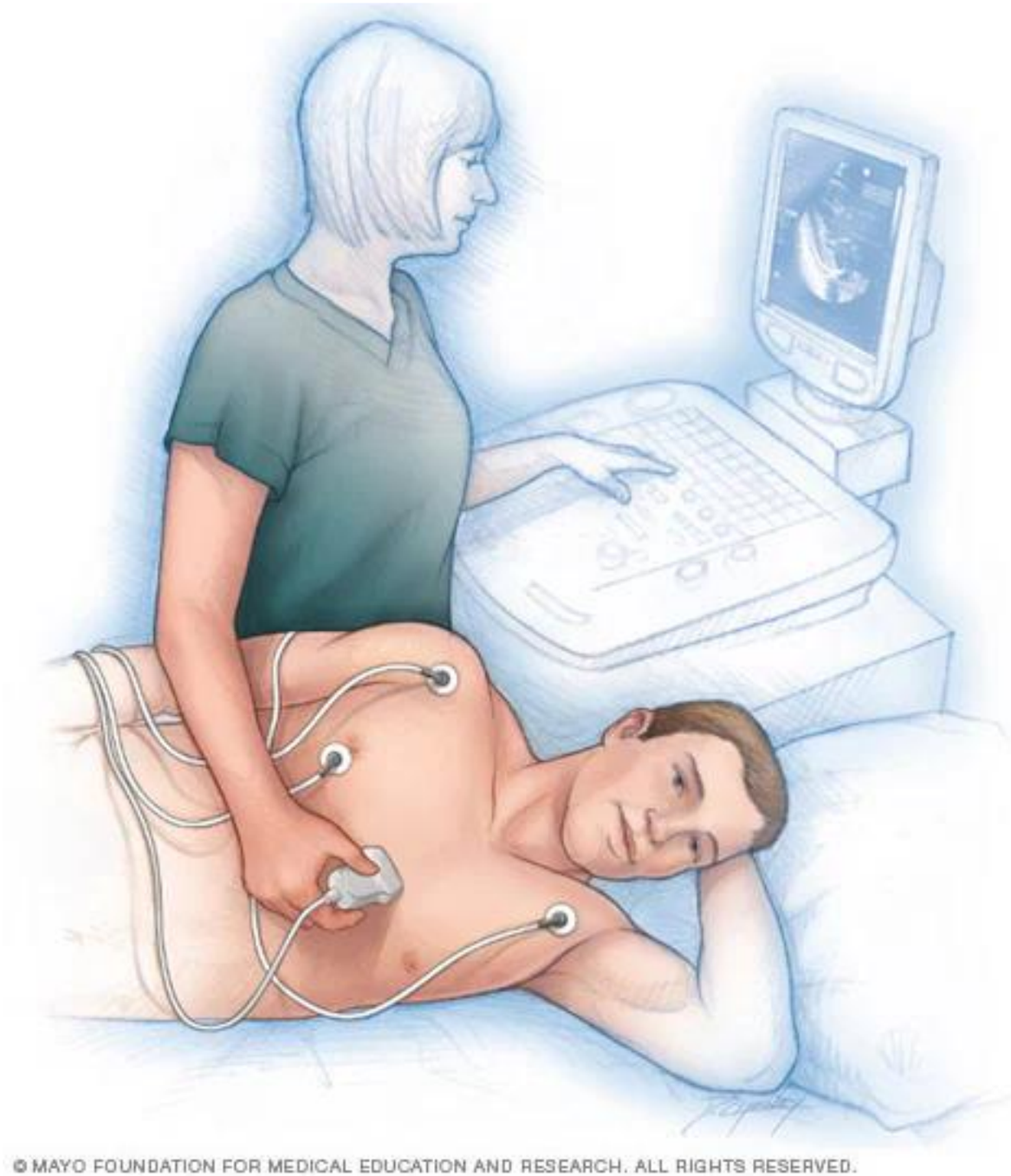
Where is the AI?

- Super-res data is limited, not standardized
- Standard ultrasound: anatomical locations are difficult to align
  - 3D imaging could help, rarely used in the clinic

- Where is AI helping?
  - Well-known, clear anatomy (heart, fetus)
  - Cross-translation (with MRI or CT)

Echocardiogram: currently manual intensive



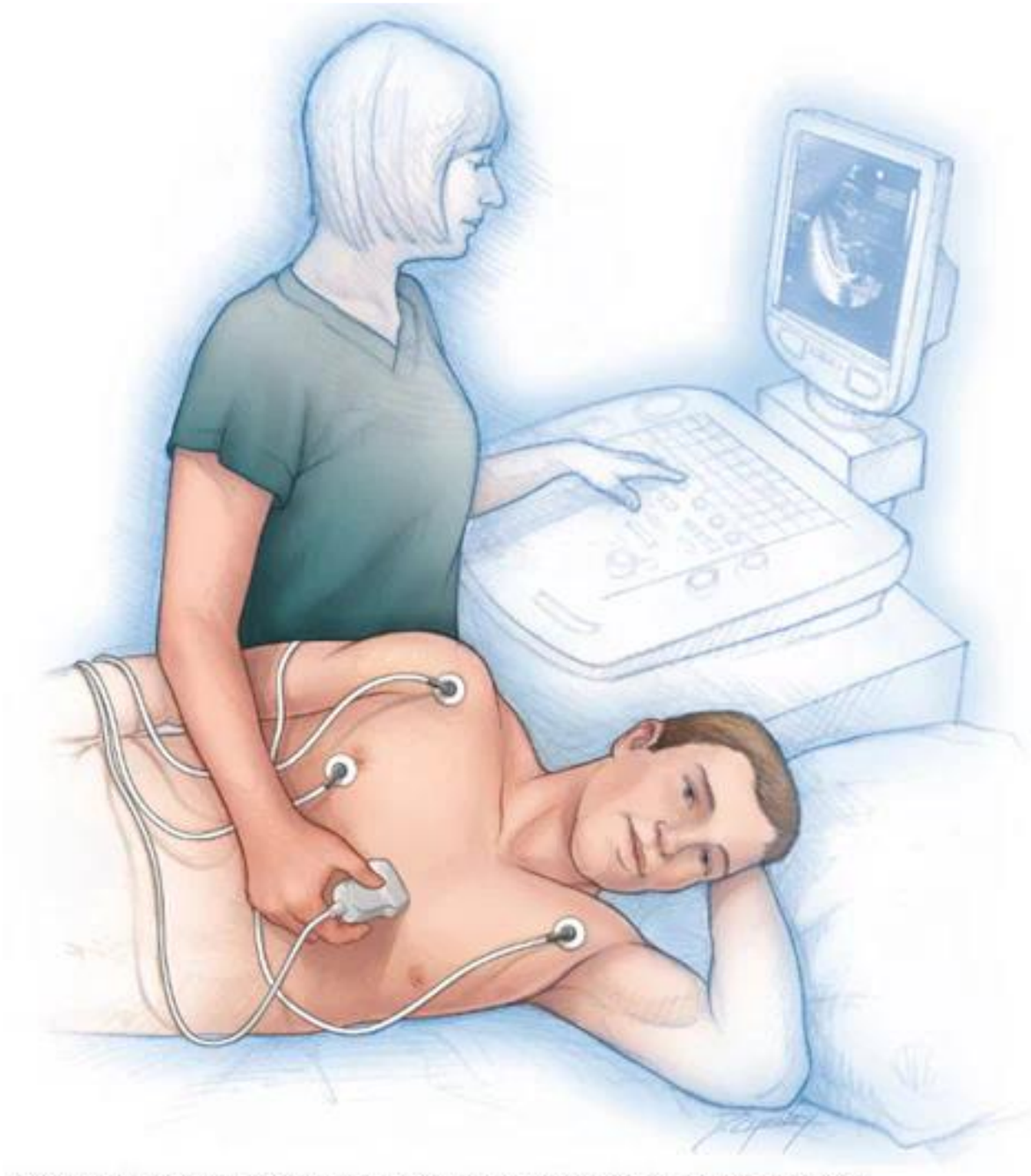


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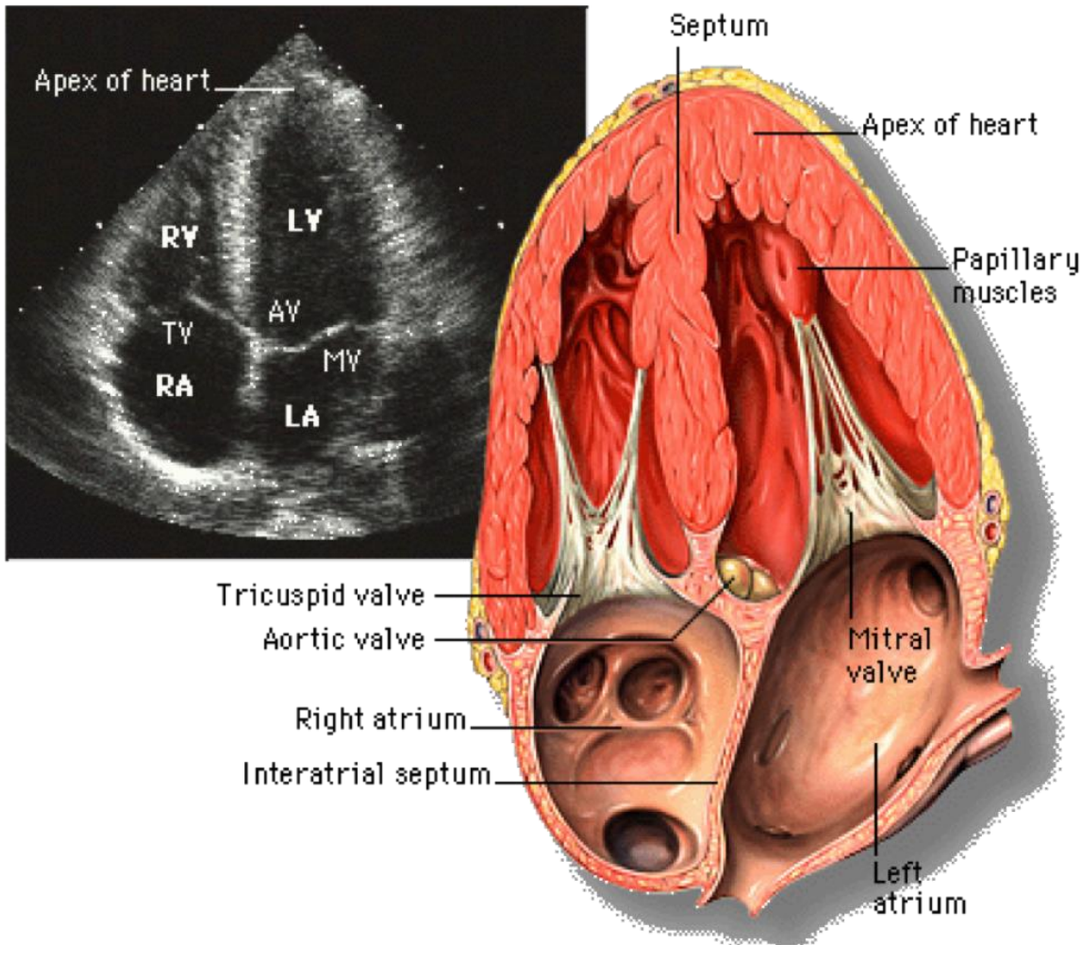
Echocardiogram: currently manual intensive

- Evaluate heart function from 2D images at different phases of heart cycle
  - Evaluate LV ejection fraction, etc.
- Manual annotation, lots of clicking, operator dependent

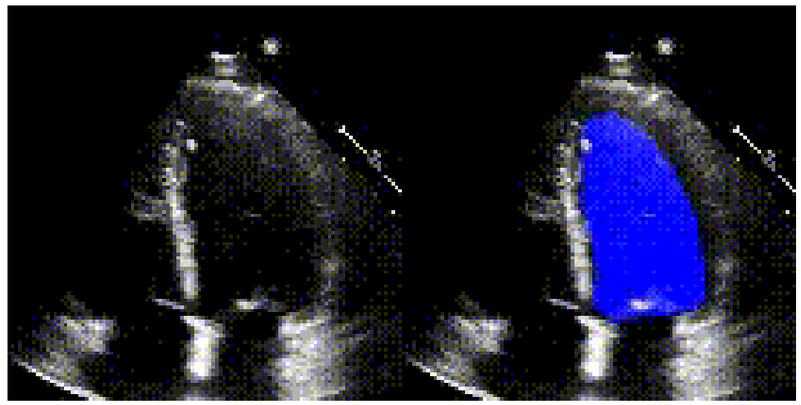


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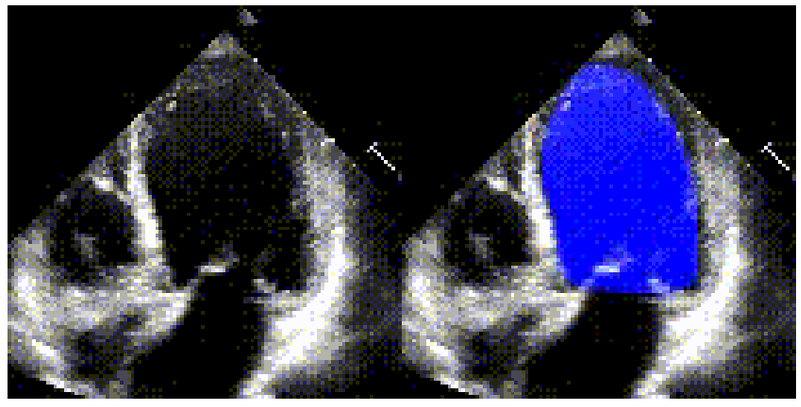
EchoNet: automating echocardiograms



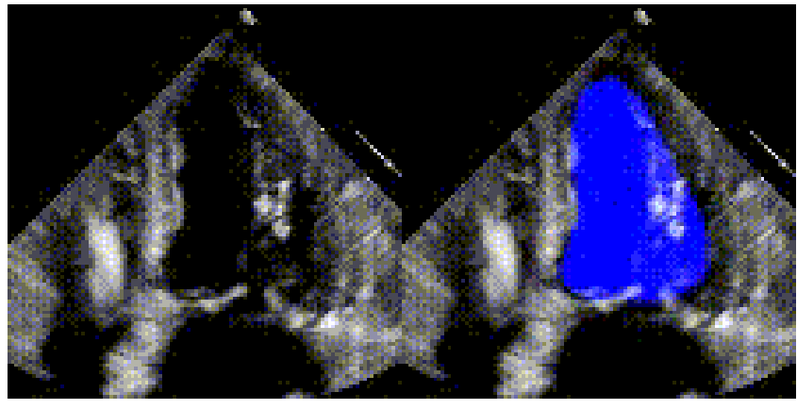
Normal



Low ejection fraction



Arrhythmia



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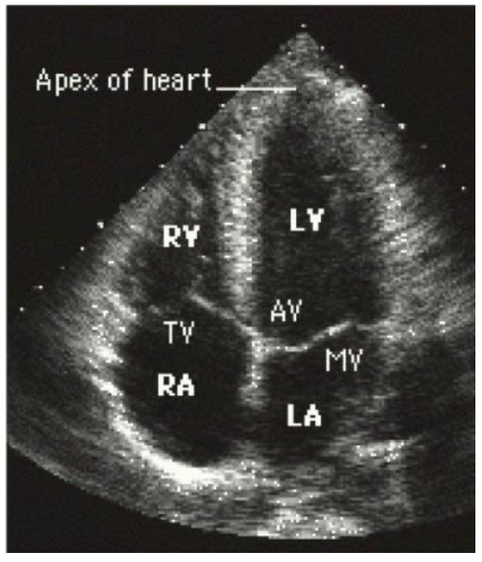
https://github.com/echonet/dynamic

Do we need echocardiograms?



ECG

predict



electrocardiogram

Q: Is this the right prediction task?

"Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made precise." - John Tukey

Poterucha, et al., *Nature* **644**, 221–230 (2025)

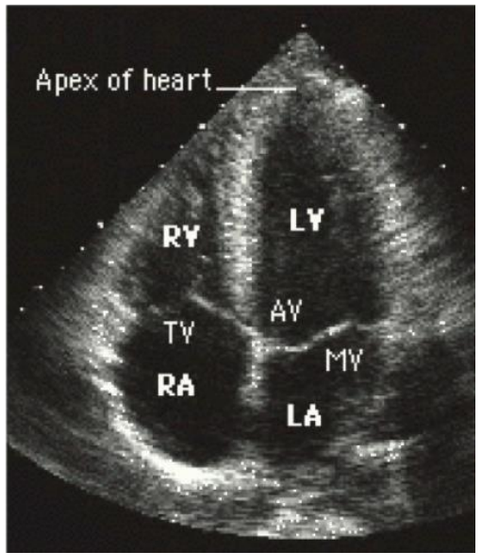
Obermeyer, et al., *Nature* **655**, 210–218 (2026)

Do we need echocardiograms?

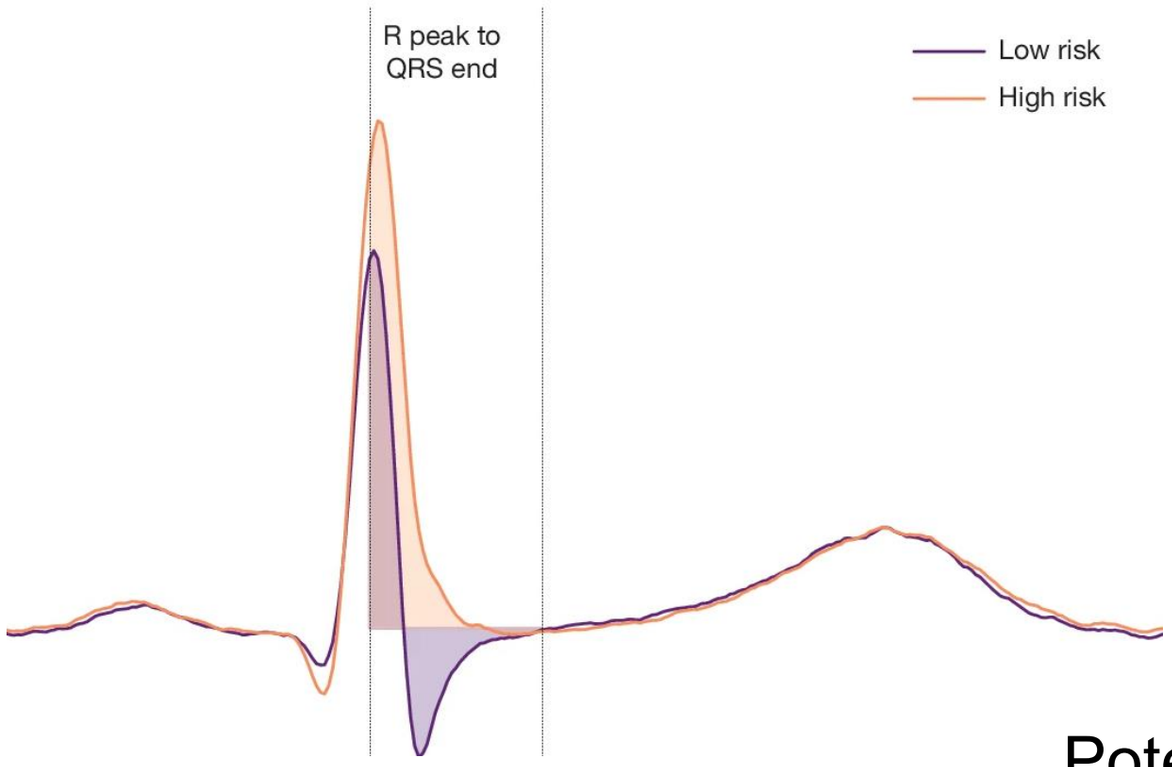


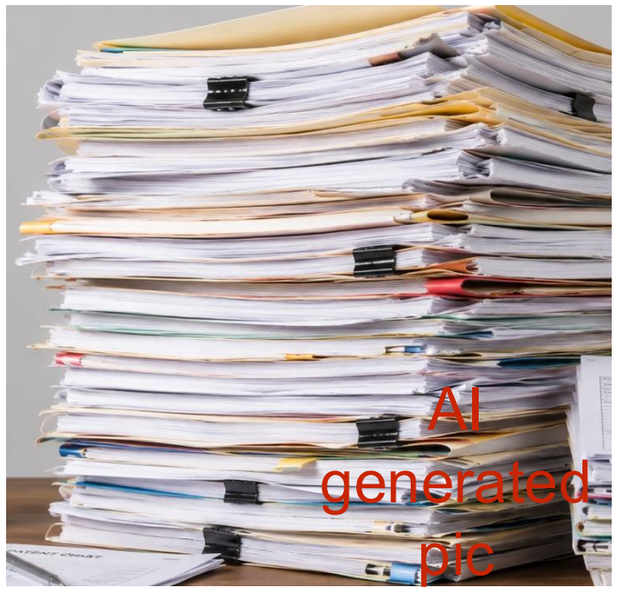
ECG

predict



electrocardiogram



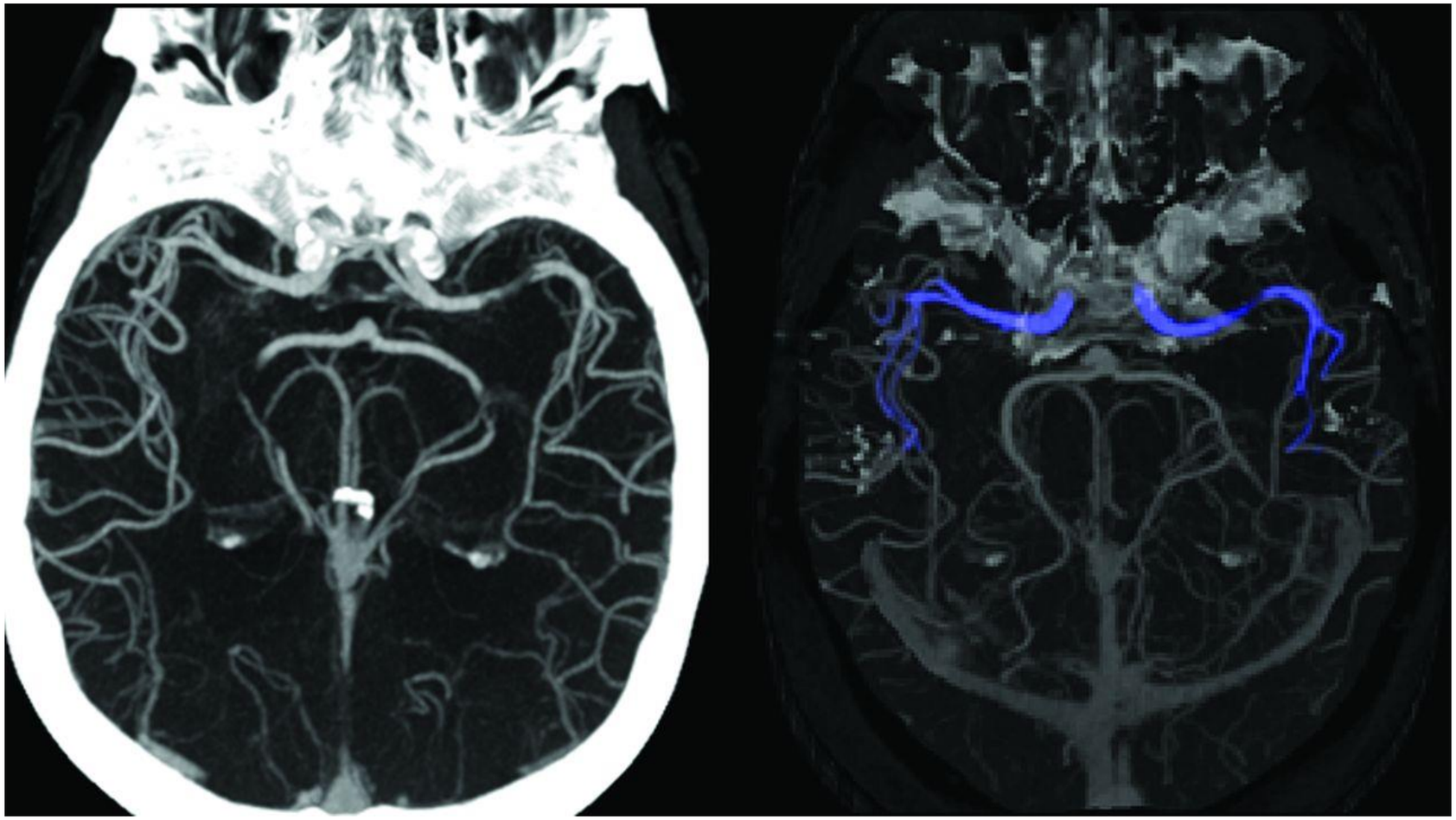


outcomes

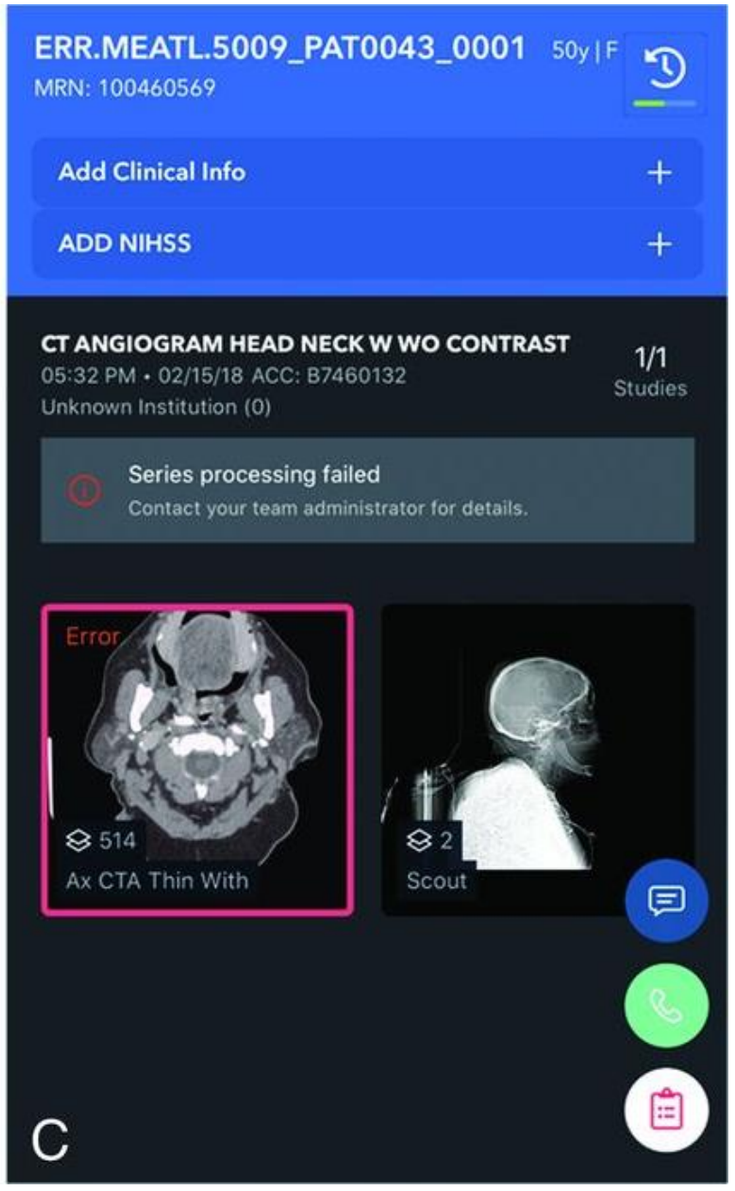
Poterucha, et al., *Nature* **644**, 221–230 (2025)

Obermeyer, et al., *Nature* **655**, 210–218 (2026)

AI for ischemic strokes (CT, not ultrasound)



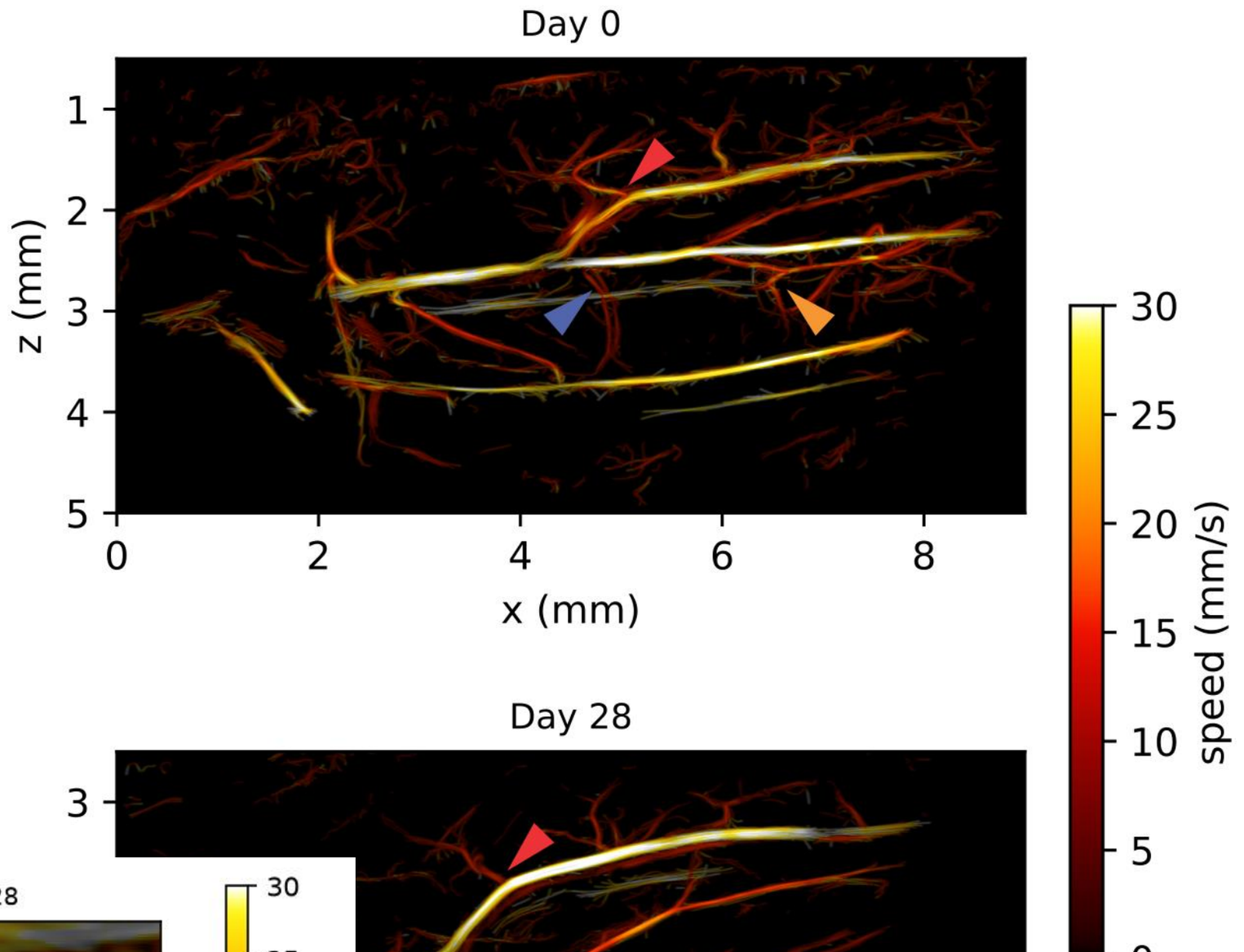
Stroke detection (viz.ai)

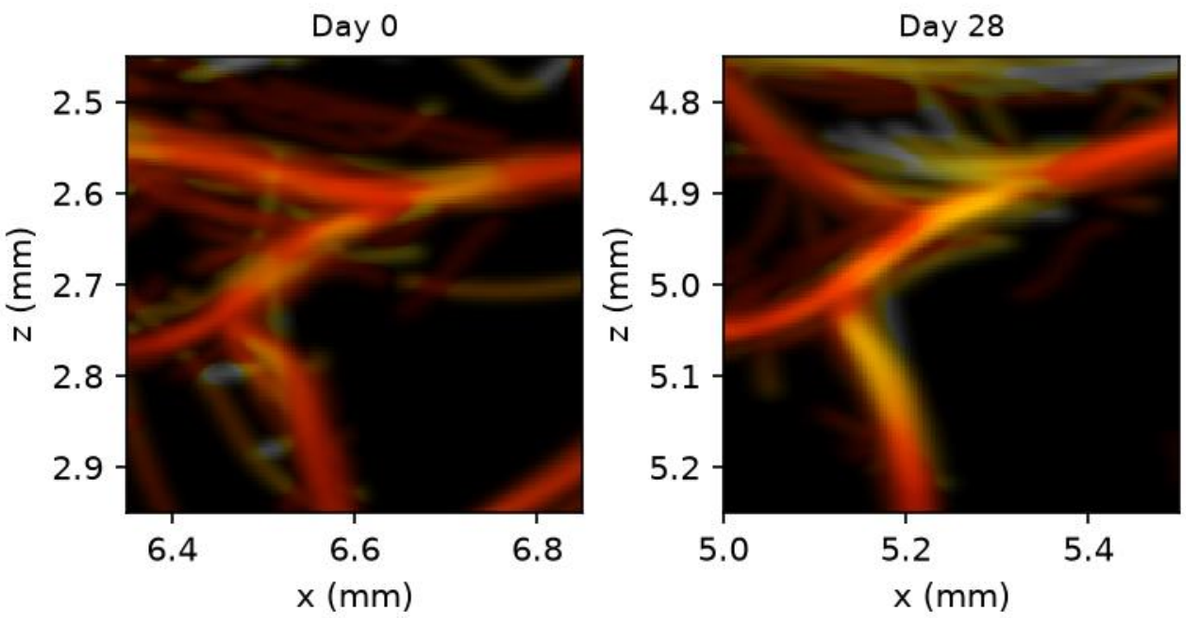


Yahav-Dovrat, et al., *AJNR Am. J. Neuroradiol.* **42**, 247–254 (2021)

Can AI predict changing vascular structure?

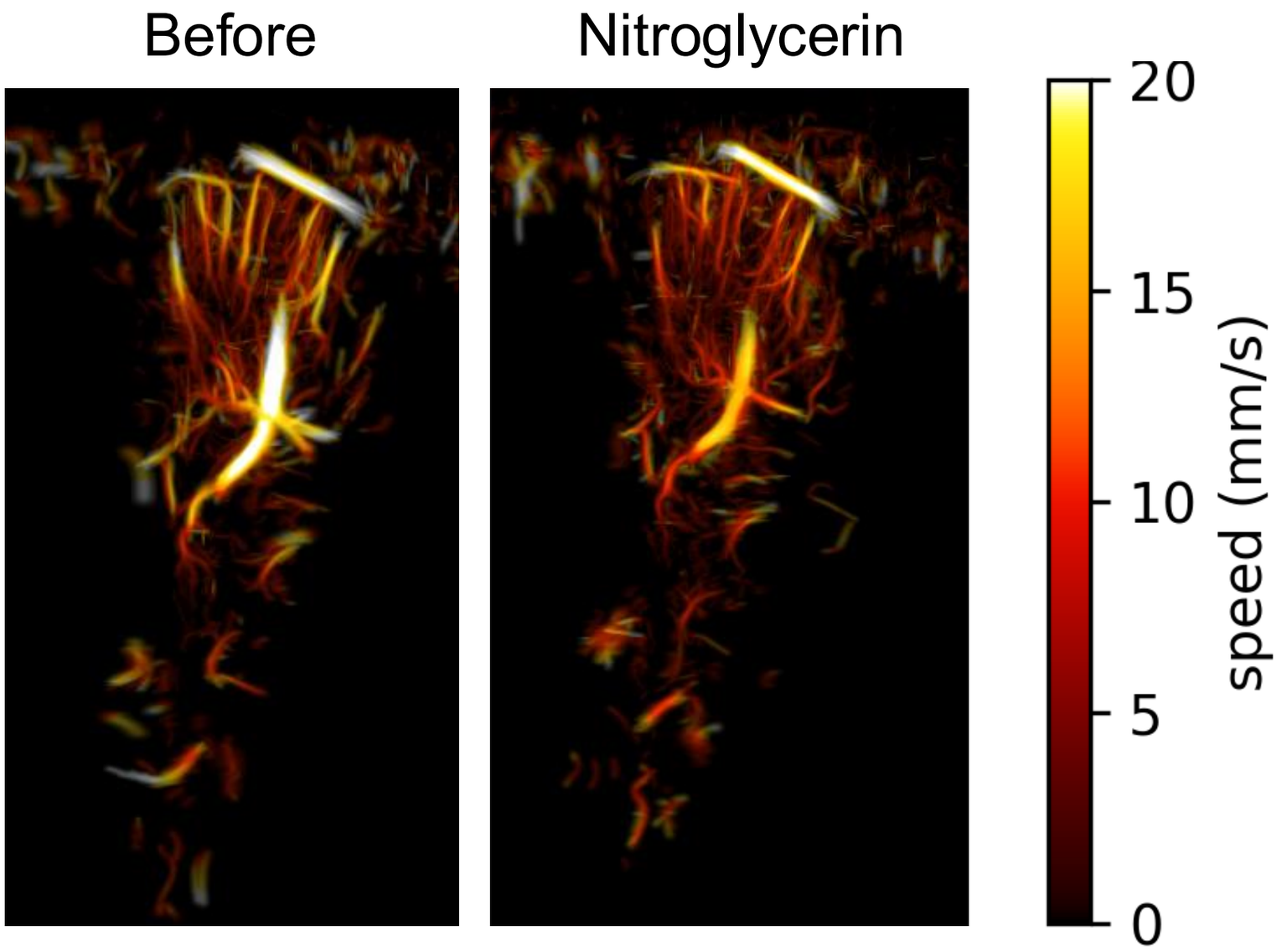
- Healthy mouse hindlimb over 4 weeks
- Can AI predict vascular network, changes?





Can AI explain how networks redistribute?

- Can AI explain complex changes in vascular flow?
- Perturb with vasodilators, age, transgenic models, etc.



Q: What else can we learn from super-resolution ultrasound images?

with Akhilesh Kotiyal and Amynah Pradhan

Check time

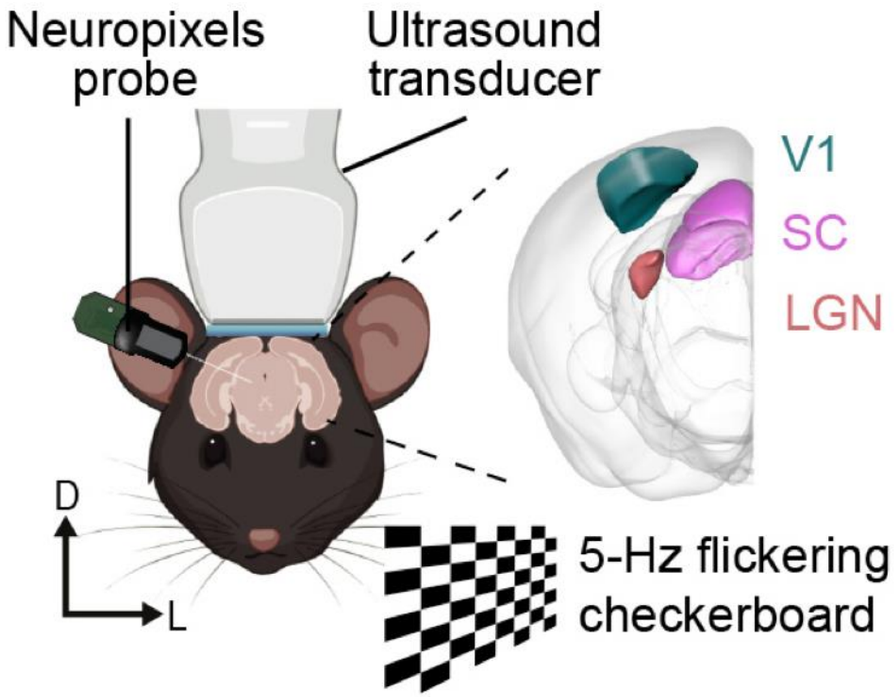
T < 1:45pm

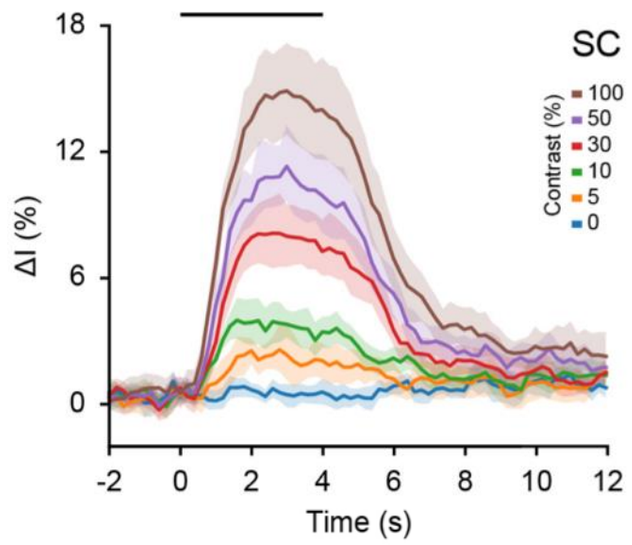
T >= 1:45pm

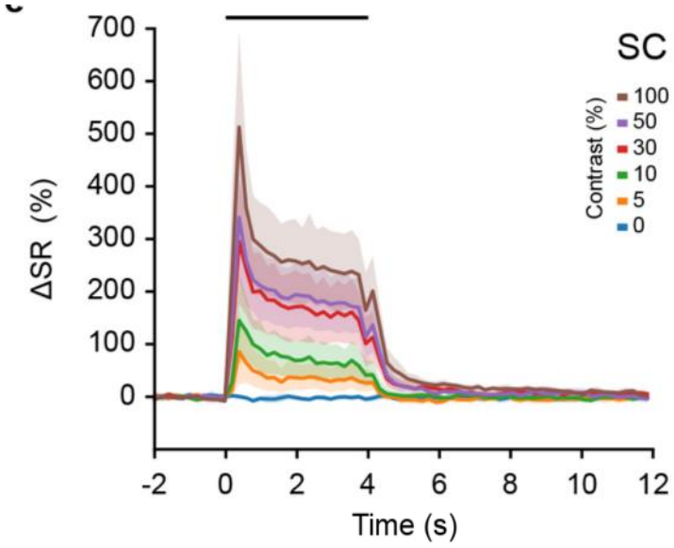
Functional brain imaging

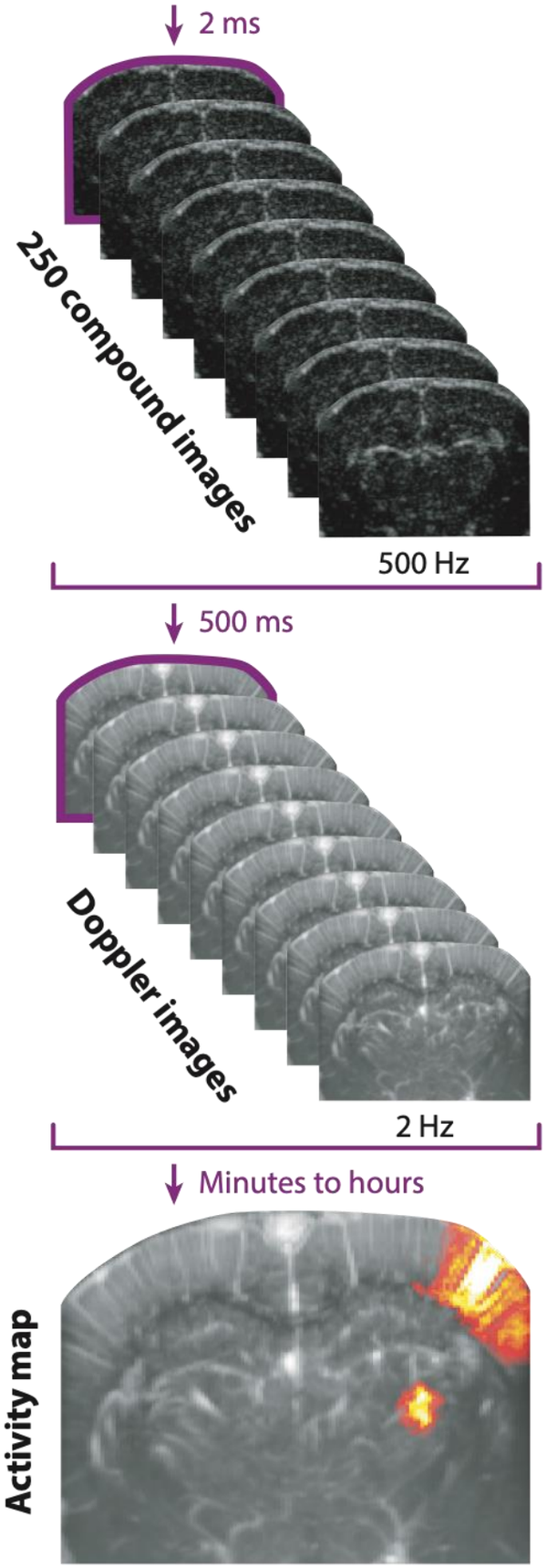
Skip to last section
(ask me afterwards)

fUS: “fMRI” for ultrasound





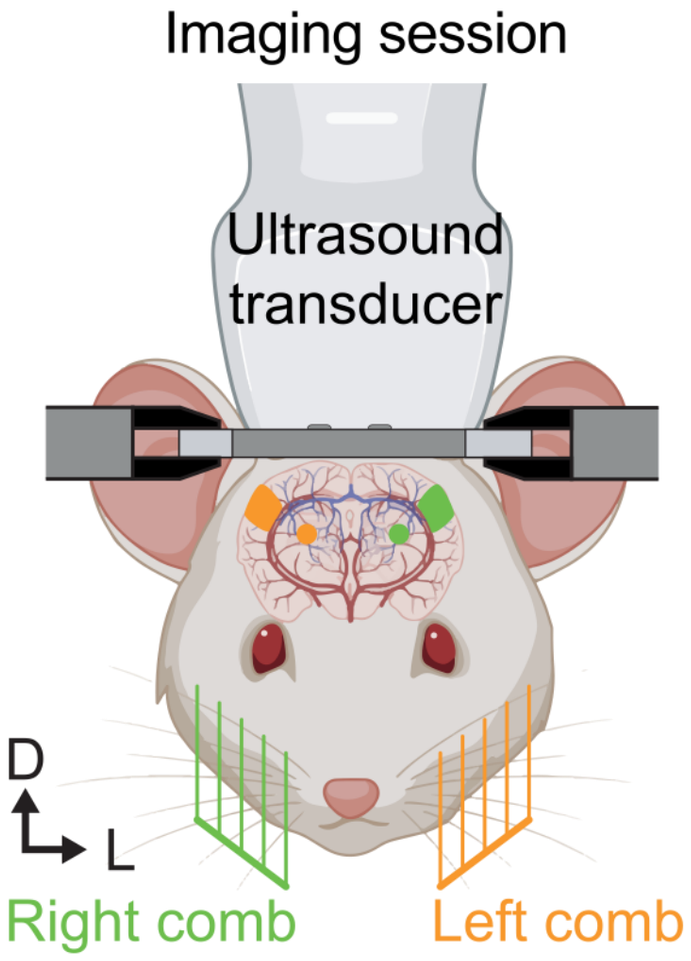




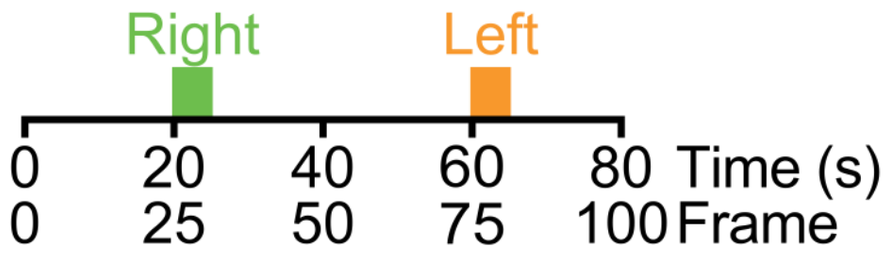
SC: superior colliculus
LGN: lateral geniculate nucleus
VPM: ventroposterior medial nucleus of the thalamus

Lambert, *et al.*, *Imaging Neuroscience* **45**, 491 (2025)
Montaldo, *et al.*, *Annual Review of Neuroscience* **45**, 491 (2022)

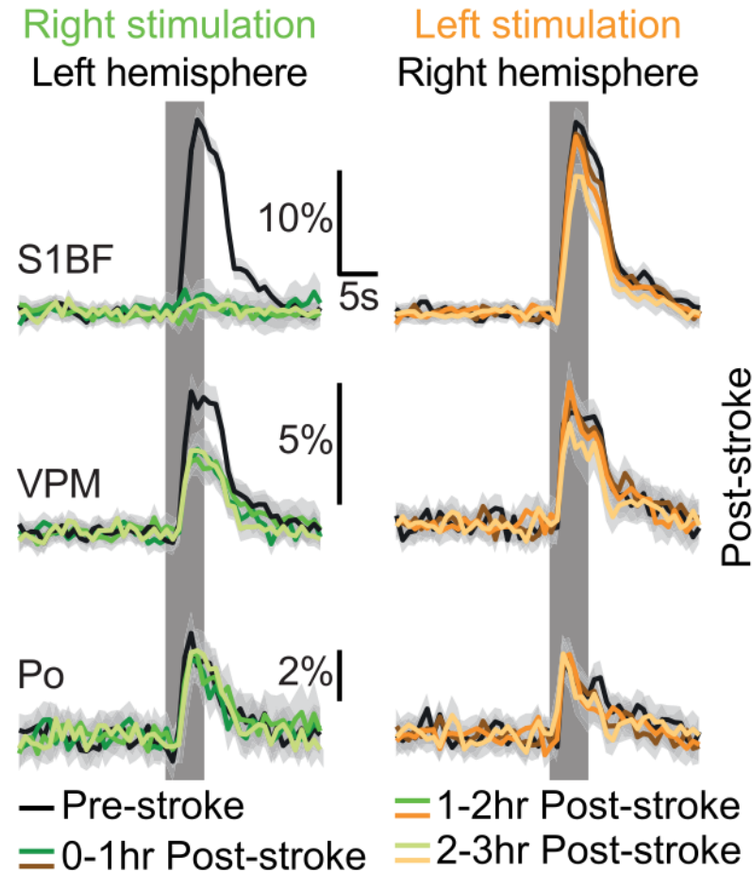
Functional ultrasound imaging of stroke in rat



Whisker stimulation paradigm
- 20° deflection / 5Hz / 5s
- Alternation Right/Left
- 45 stimuli/whisker/hr



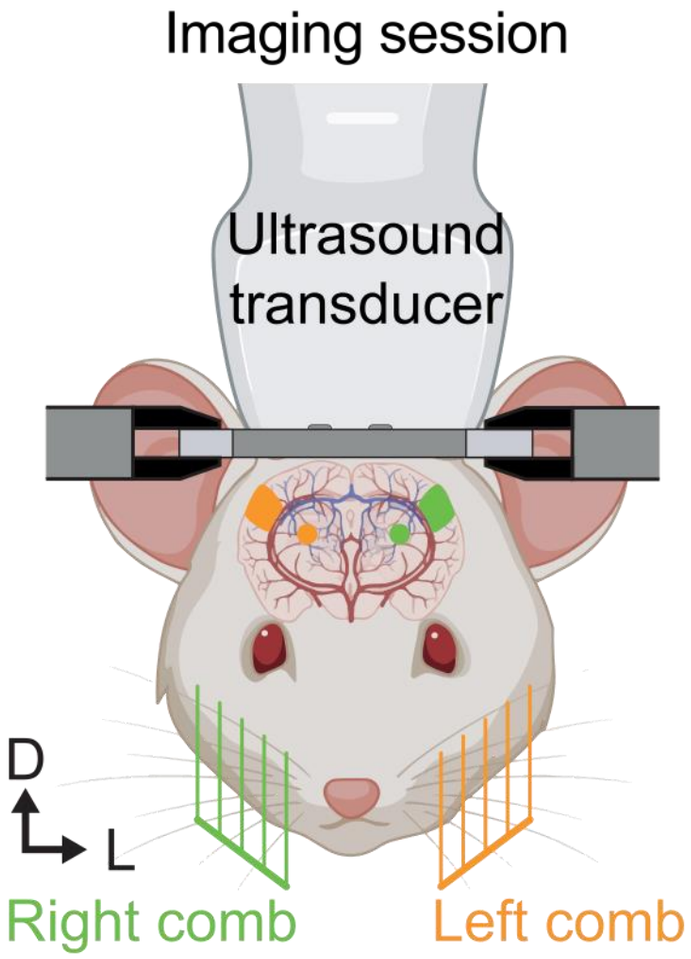
Imaging session
- 1hr Pre-stroke (4,500 frames)
- MCA occlusion
- 3hrs Post-stroke (13,500 frames)

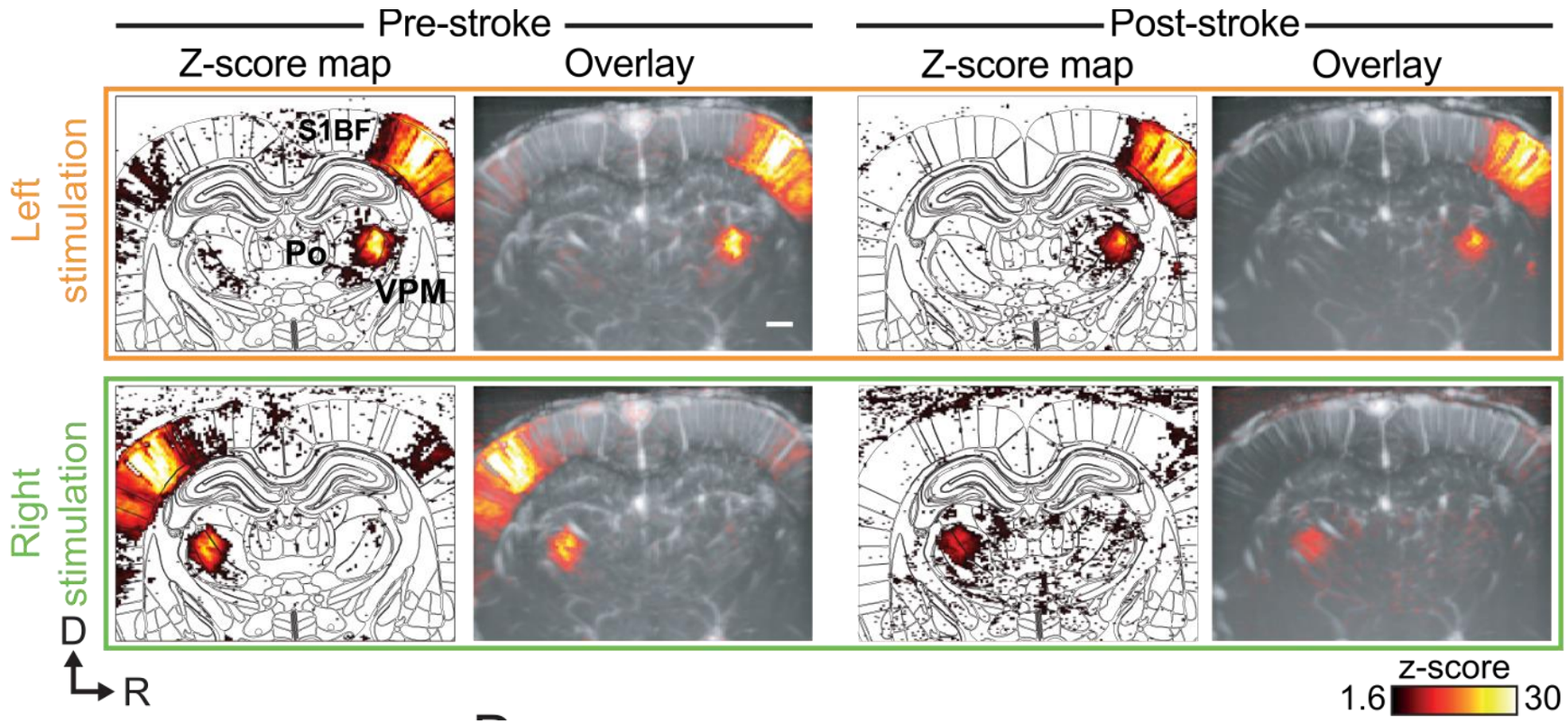


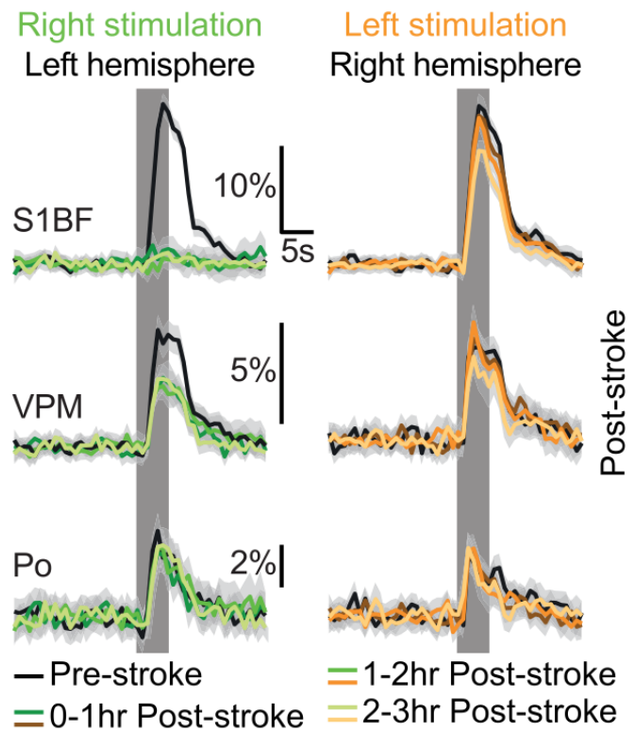
S1BF: somatosensory barrel-field cortex
Po: posterior nucleus of the thalamus
VPM: ventroposterior medial nucleus of the thalamus

Brunner, *et al.*, *eLife* **12**, RP88919 (2023)

Functional ultrasound imaging of stroke in rat



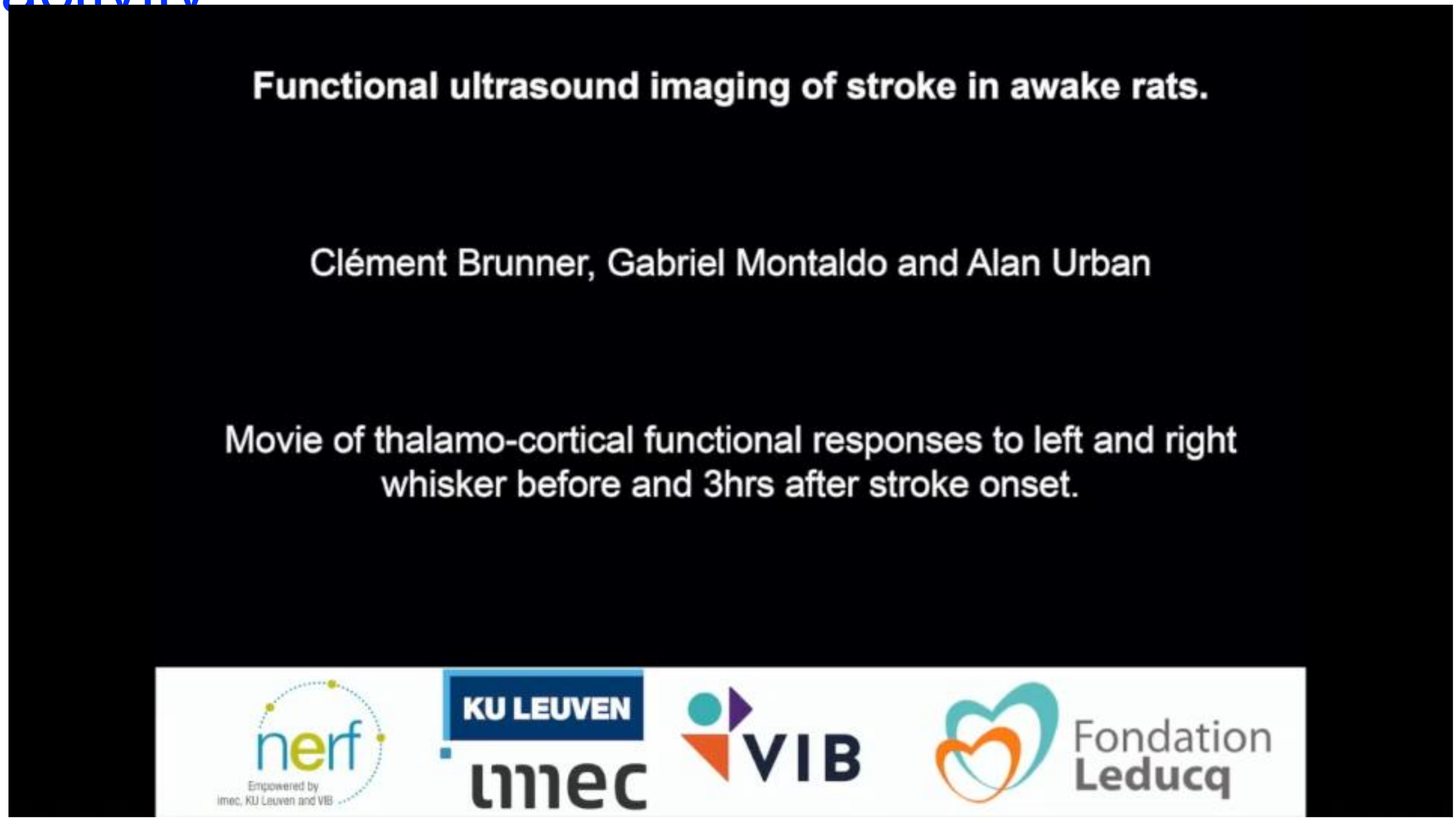




S1BF: somatosensory barrel-field cortex
Po: posterior nucleus of the thalamus
VPM: ventroposterior medial nucleus of the thalamus

Brunner, *et al.*, *eLife* **12**, RP88919 (2023)

Functional ultrasound (fUS) imaging of neural activity



Biology questions are not “well posed”: can AI help?

What else can AI do for biology?

THE NEW YORKER

ANNALS OF MATHEMATICS

THE YEAR MATH CHANGED FOREVER

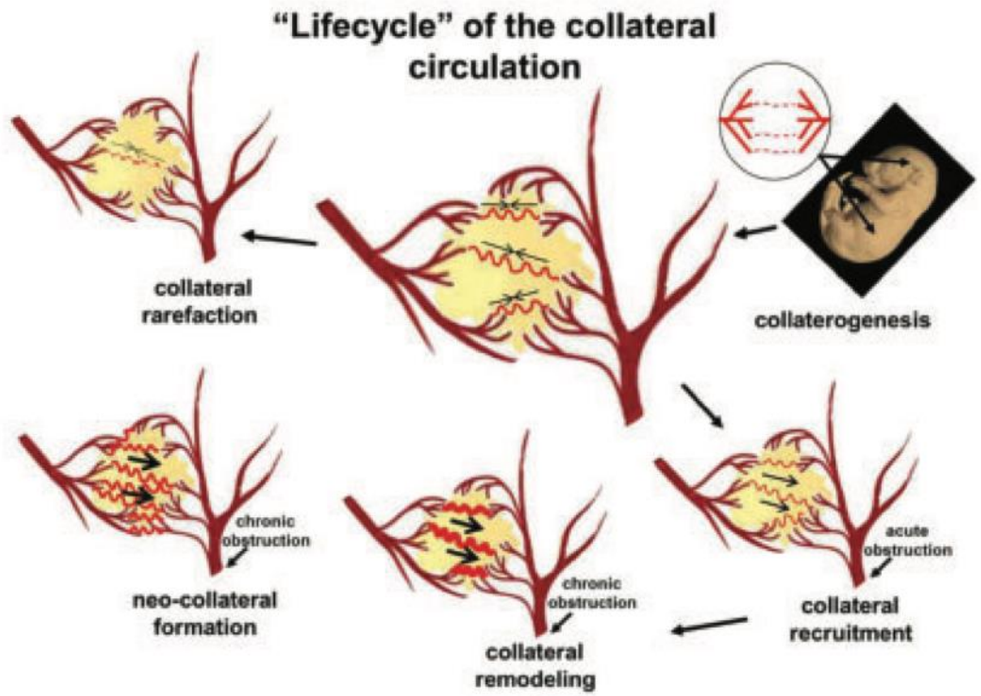
A.I. is solving problems that stumped the field for decades. Mathematicians look to Terence Tao for guidance on their altered world.

By Rivka Galchen

November 1, 2026

"The landscape had now changed to one of proof abundance" - Terence Tao

- Maybe proof abundance is what biology needs
- Can we state problems in biology clearly enough for proofs?

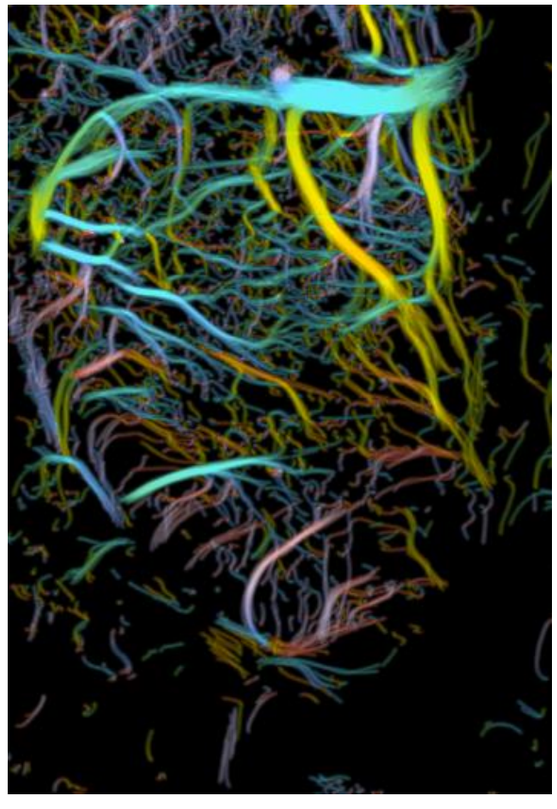


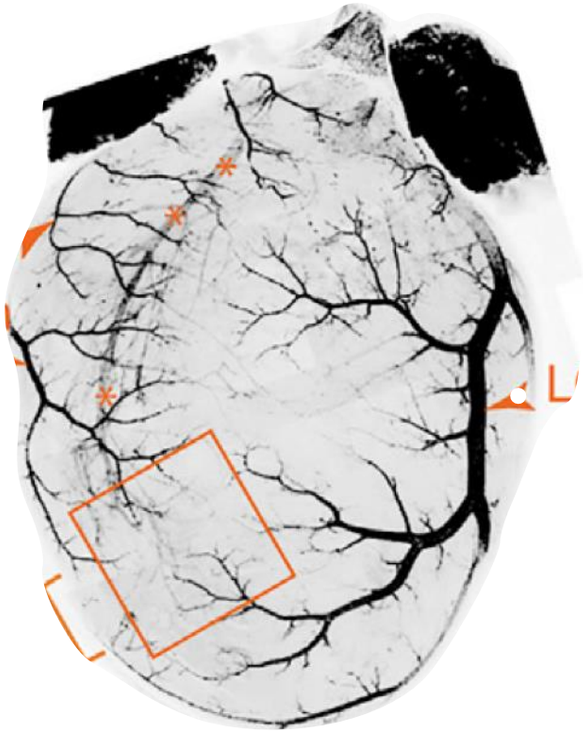
Biology relies on emergence: local decisions lead to emergent structures

1. Can we predict emergent (robust) structures from simples rules?
2. Can we predict their failure in aging, disease?

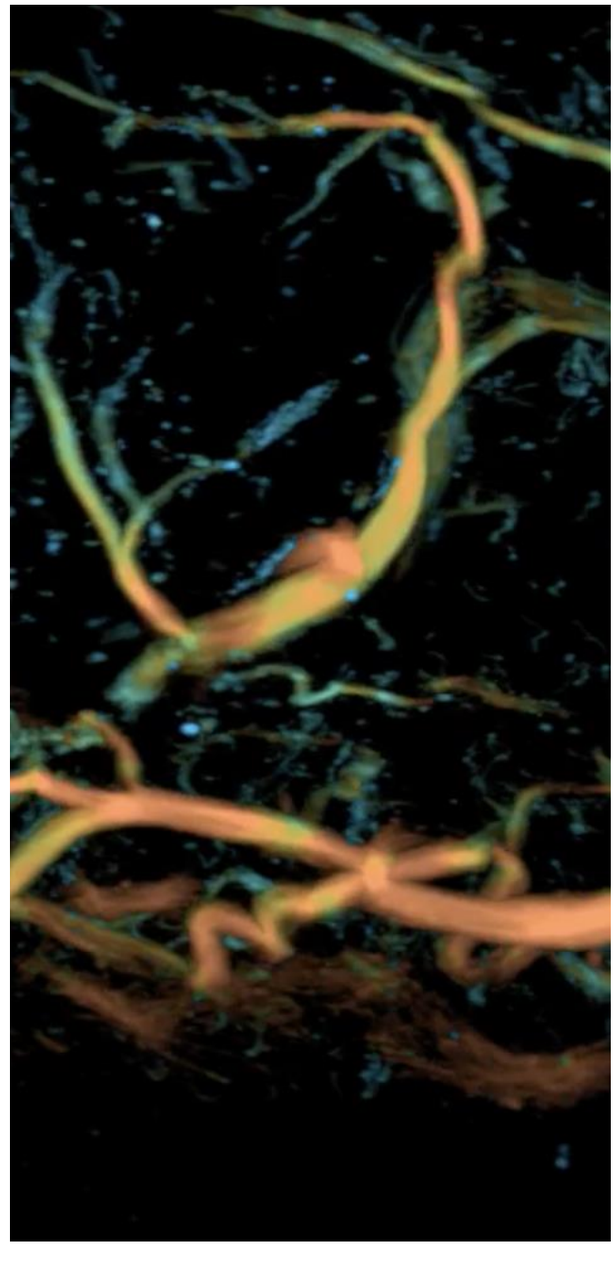


Neural organization



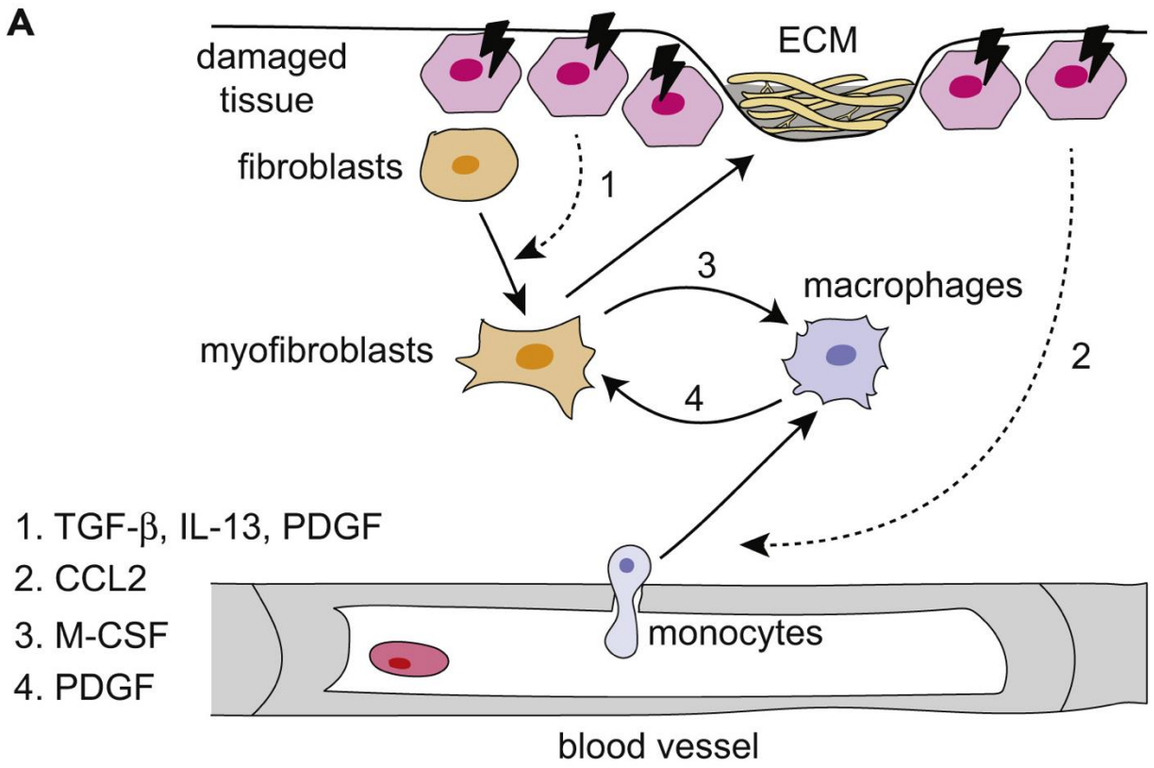


Vascular organization

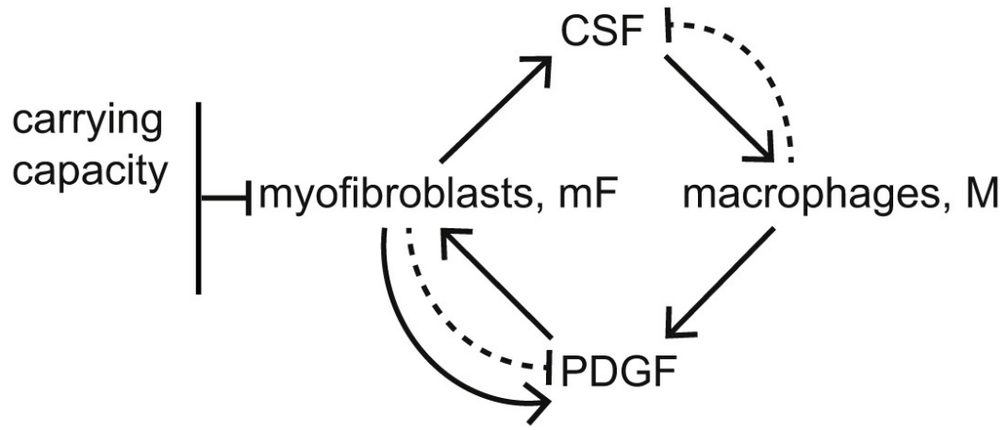


Repair and healing

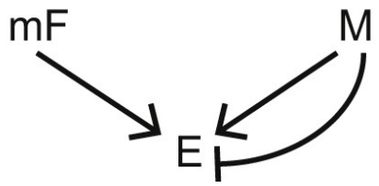
Example: phase diagram of repair



Biology schematic
12+ variables



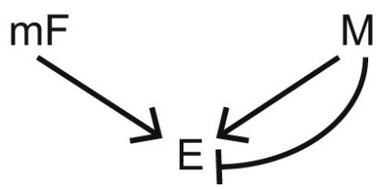
Simple circuit



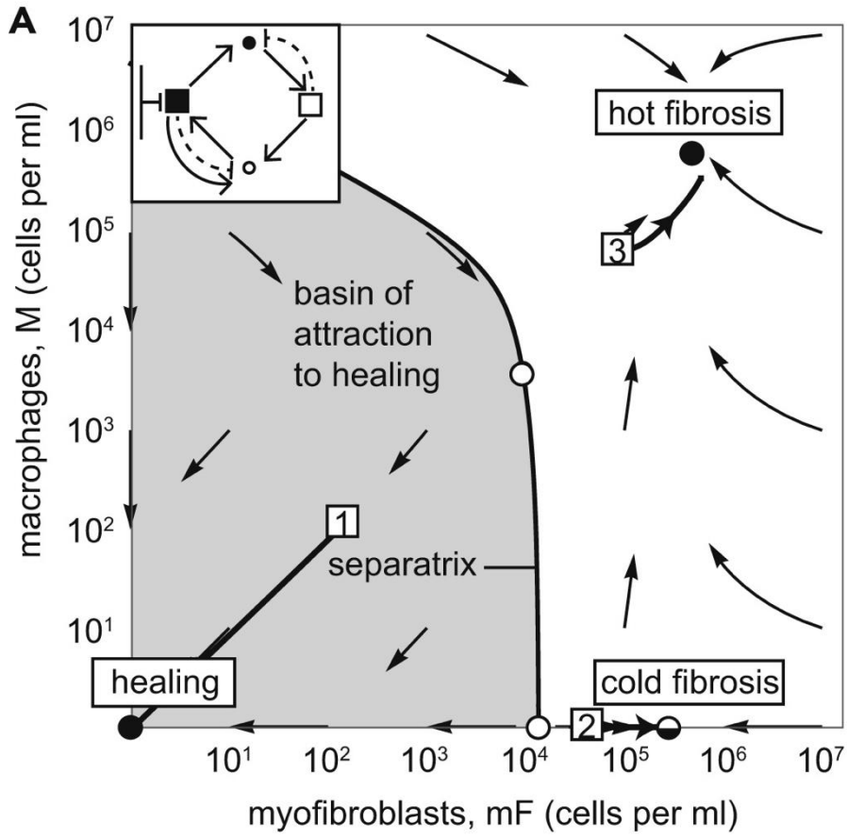
Even simpler circuit

Adler, et al., *iScience.* **23**, 100841 (2020)

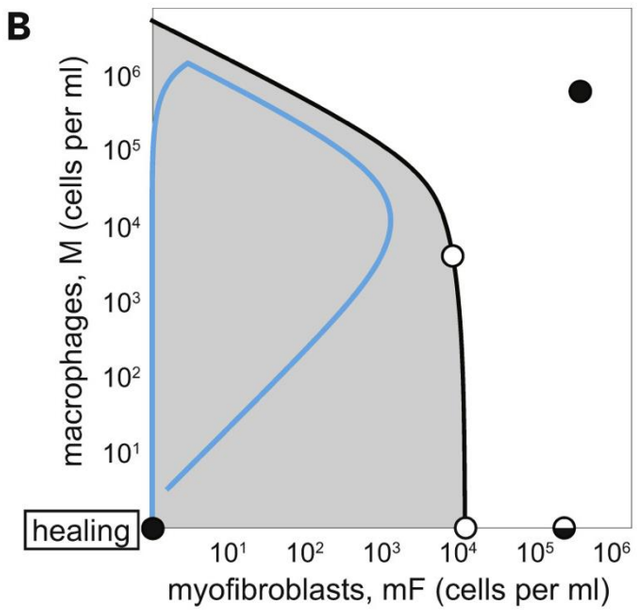
Example: phase diagram of repair



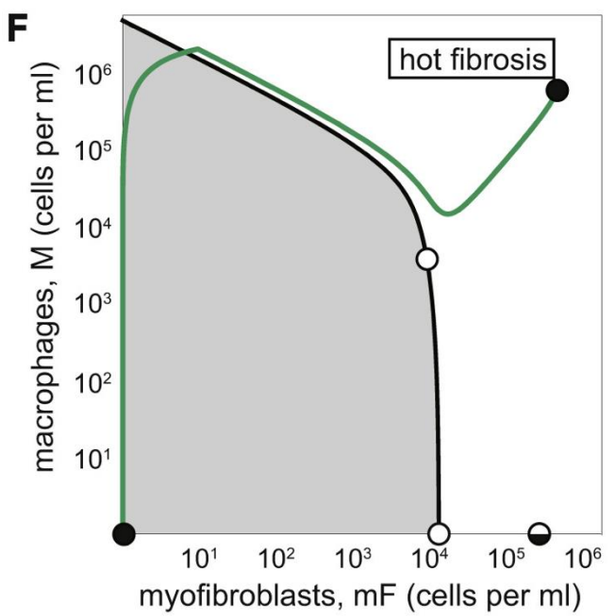
Biological circuit



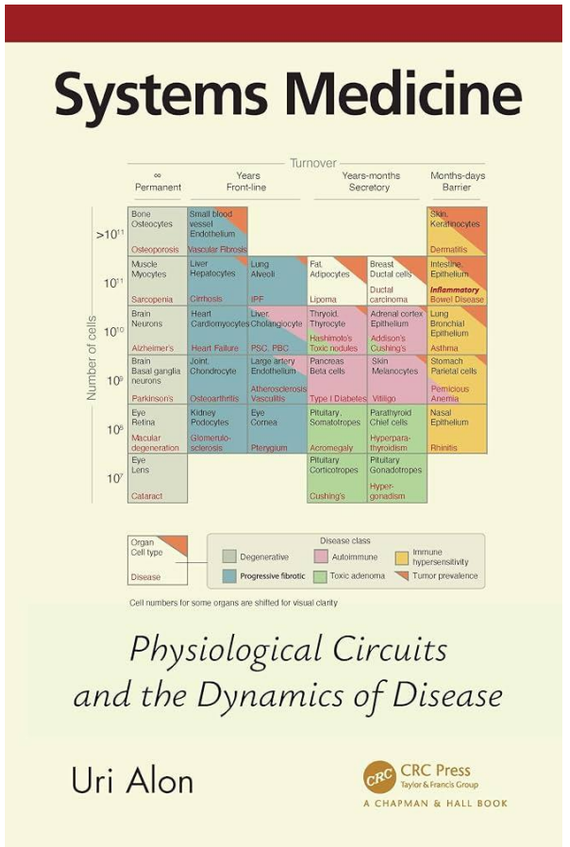
Healthy recovery



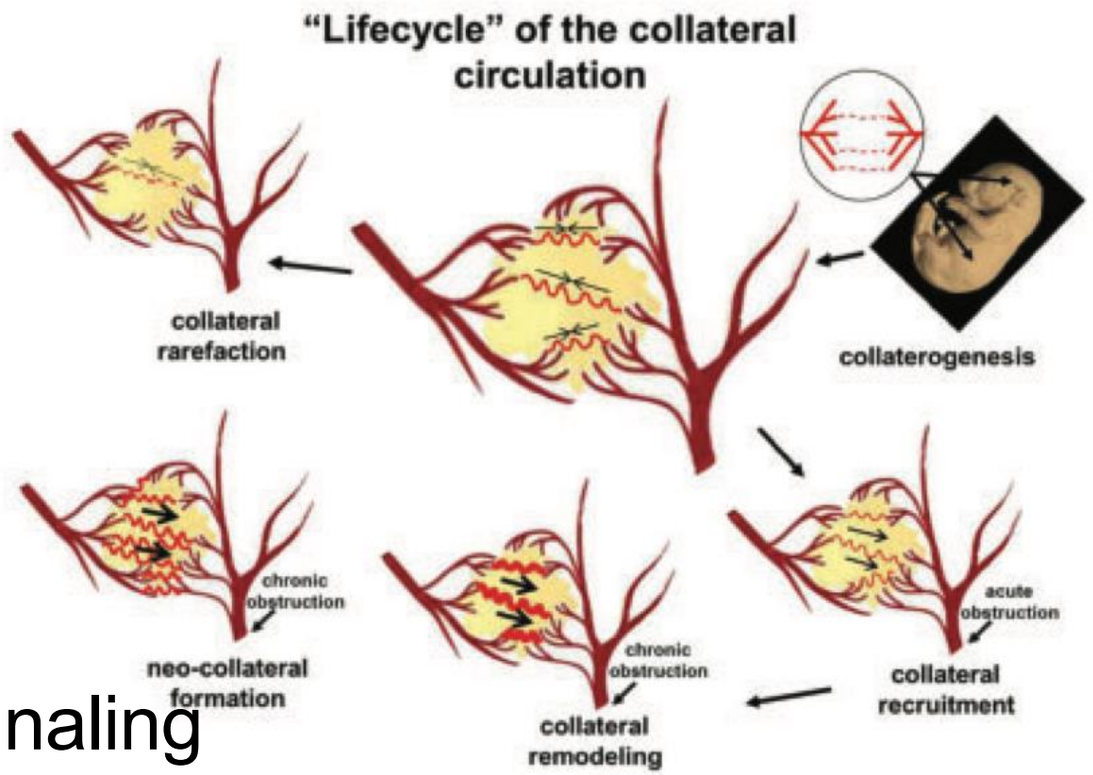
Poor recovery



Adler, et al., *iScience.* **23**, 100841 (2020)



Can we prove healthy/disease stability in more complex systems?



Quantify repair factors:

- Redistribute blood flow
- Recruit existing collaterals
- Expanding capillaries into arteries
- Growing new capillaries
- Immune recruitment/inflammatory signaling

What does a biological theory look like?

- Regions of healthy/disease stability (robust to small changes)
- Predictions of temporal perturbations (drugs) that drive the systems towards health?

Faber, *JCBFM* **45**, 1007 (2025)

Acknowledgements

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Felipe Court
Ziad Obermeyer
You
Erica Henderson
Mary Crumly
Heather Reed



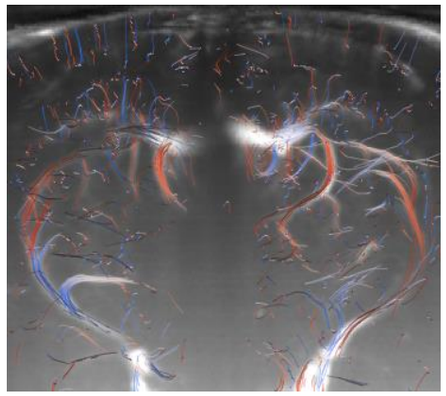
Can we monitor vascular disease down to single microvessels changes?

Project 1: Stroke (in mice)

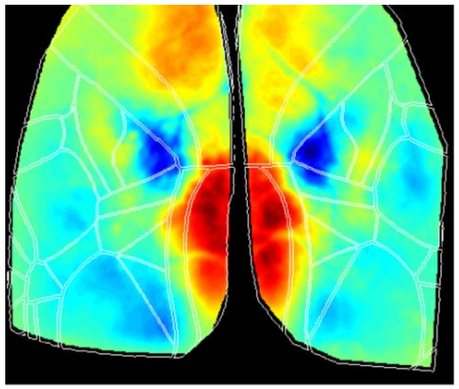
- Can we watch microvessels remodel to restore perfusion to the damaged infarct?
- How do neural circuits remap as vascular remodeling restores perfusion?

In collaboration with Prof. Jin-Moo Lee

Microvasculature



Neural circuits

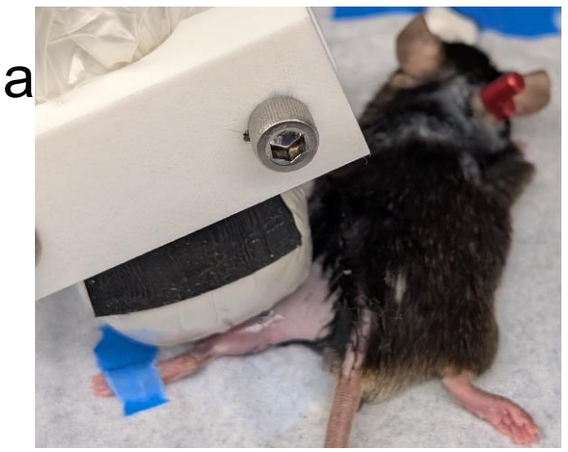


medilumine.com

Project 2: PAD and diabetes (mice)

- Can we watch collateralization dynamics after arterial blockage, and how does diabetes inhibit recovery?
- How do novel regenerative medicines work at the microvascular level?

In collaboration with Prof. Jianjun Guan

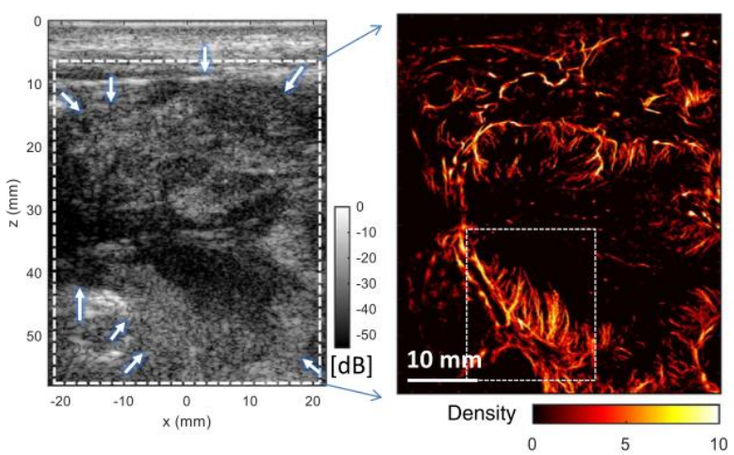




Project 3: Cancer in humans

- Can we identify benign vs malignant status and avoid biopsies
- Can we identify responders and non-responds early?

In collaboration with Prof. Quing Zhu, Malak Itani, William Middleton



Huang, *et al.*, *Phys. In Med. & Bio.* **66**, 08NT01 (2021

Cancer Research Bldg (next to library)

martilab.com