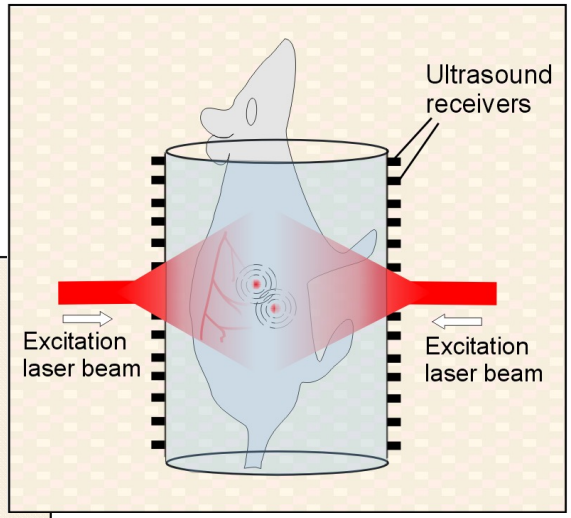
DEPARTMENT OF MEDICAL PHYSICS
AND BIOMEDICAL ENGINEERING

Ionacoustics: forward modelling & inverse problems

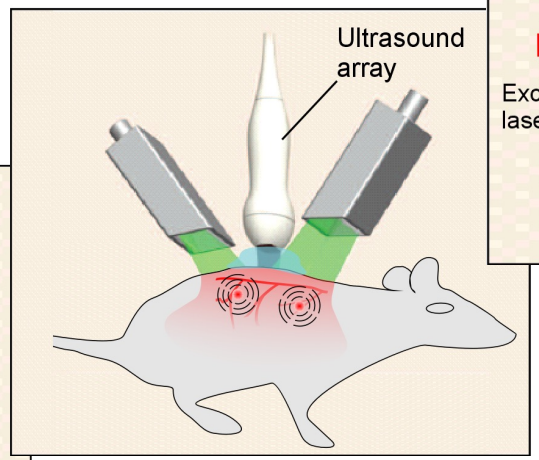
Ben Cox

Small animal photoacoustic tomography

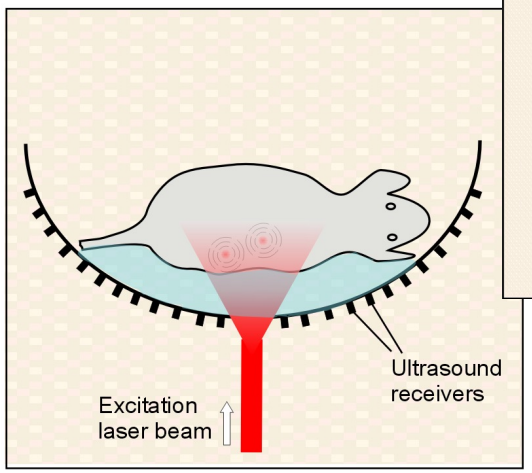
Cylindrical arrays



Linear & planar arrays

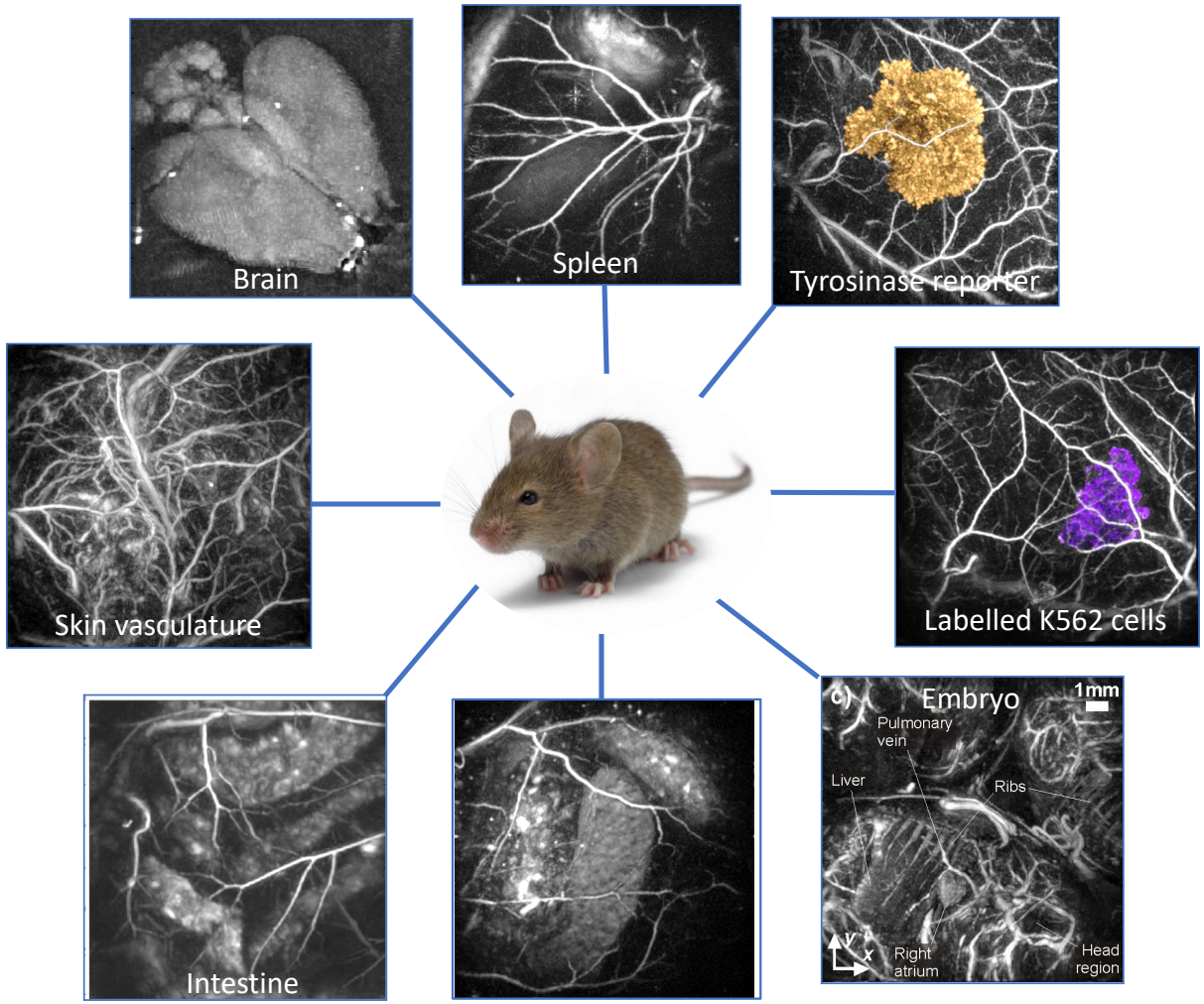


(Hemi) spherical, rotating arrays



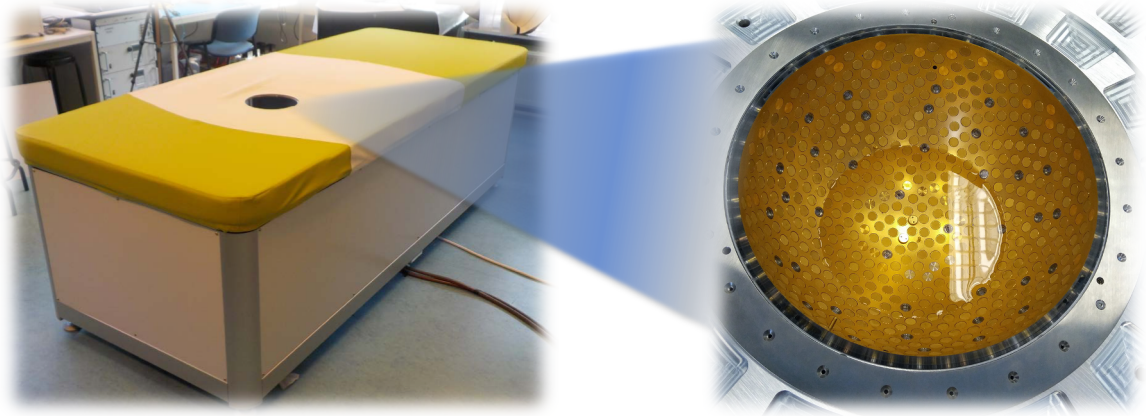
Acoustic coupling via water or gel

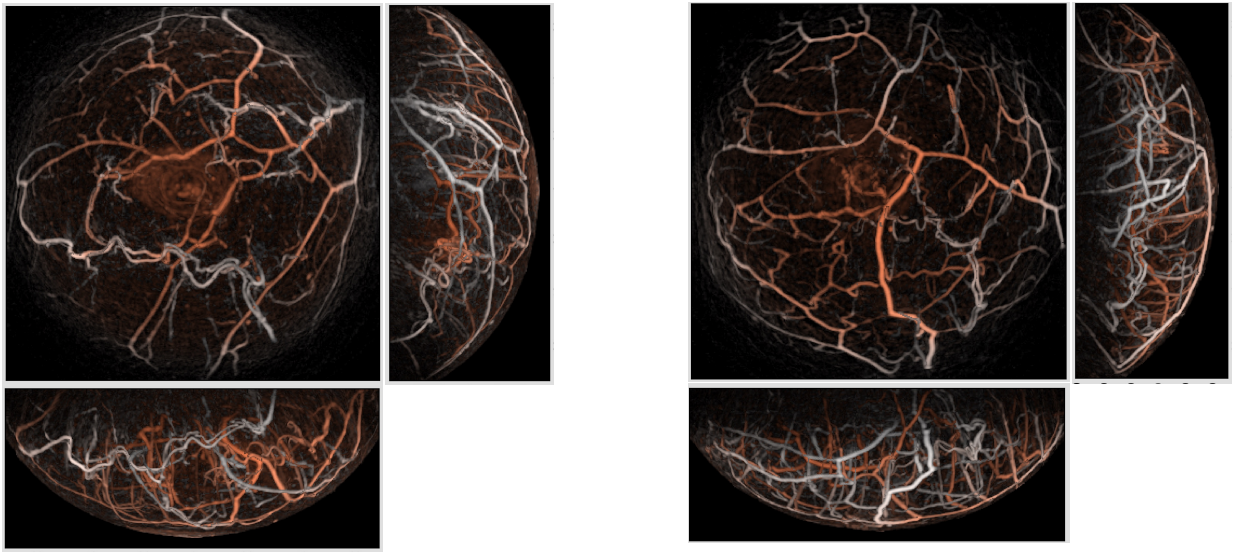
Small animal photoacoustic tomography



Images courtesy of Paul Beard, UCL

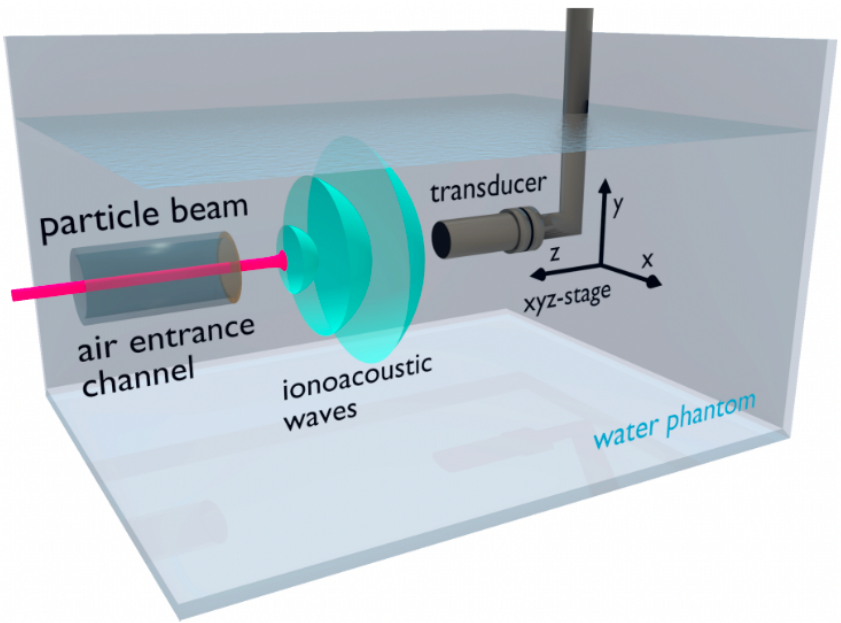
Breast photoacoustic tomography



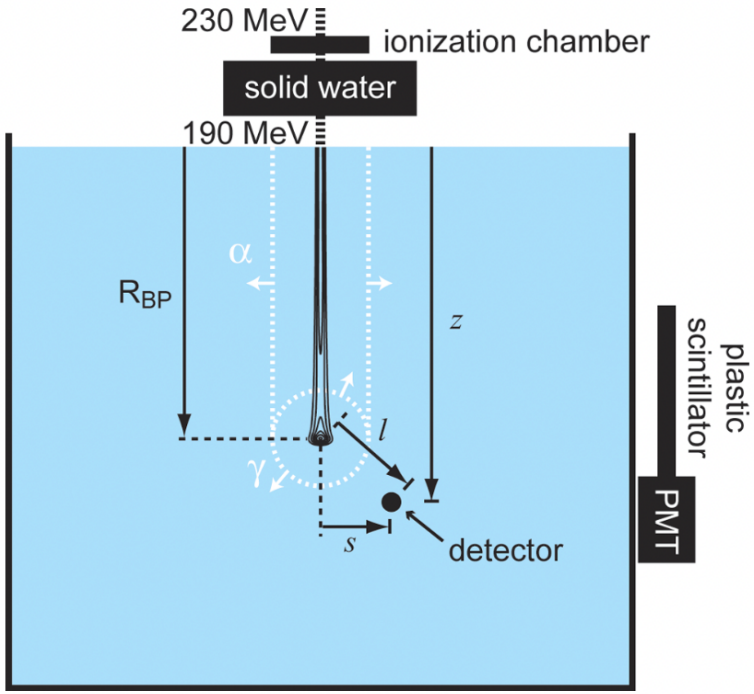


Images courtesy of Tim Op ‘t Root, PA Imaging & PAMMOTH project

Some ionacoustic experiments

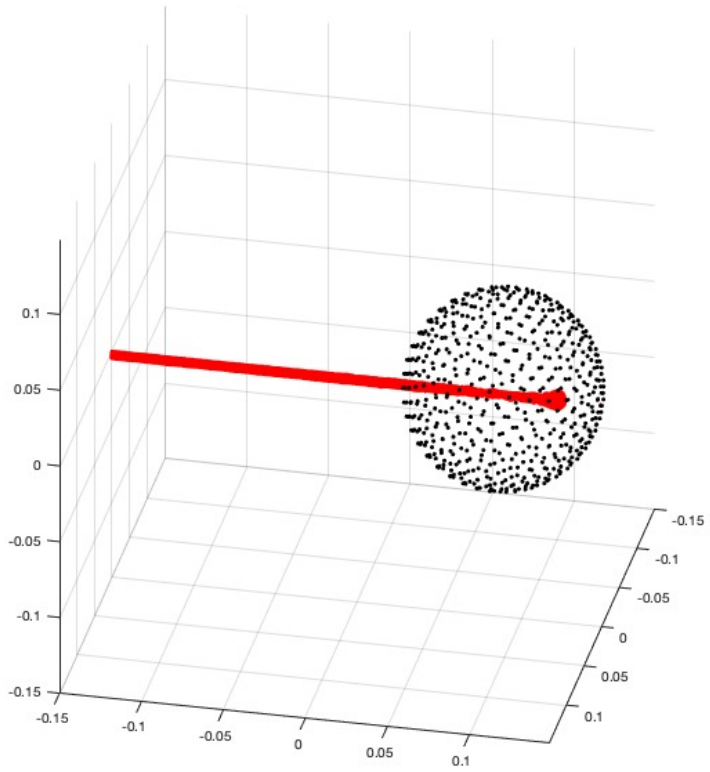


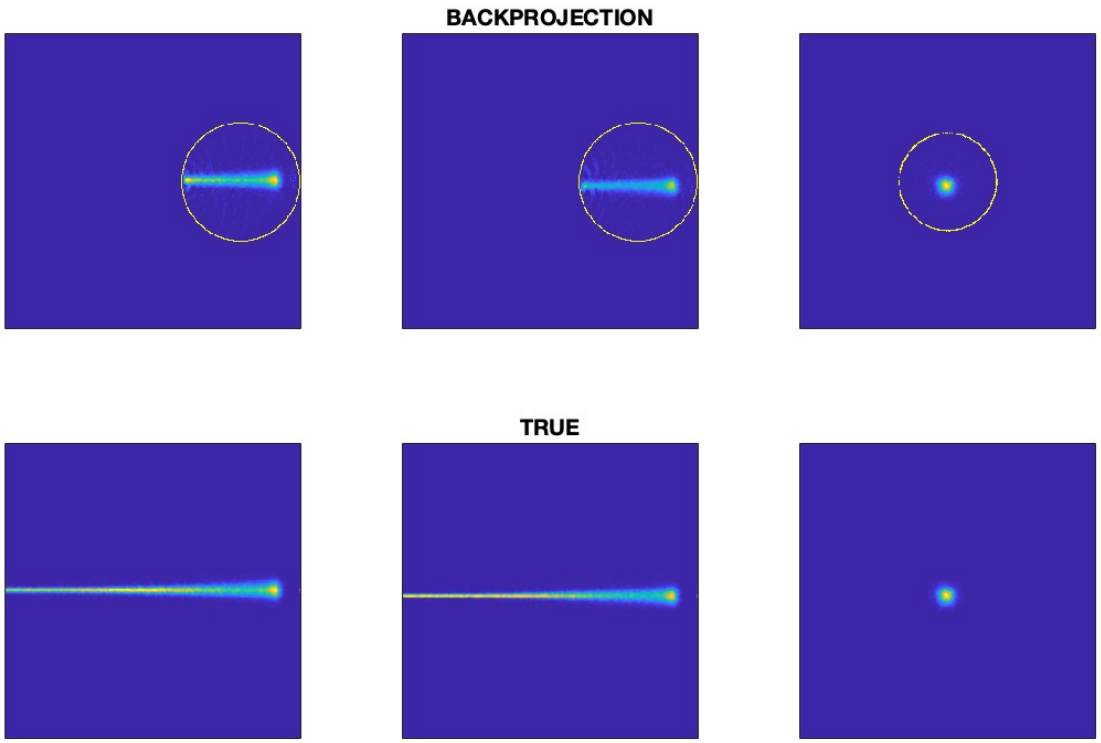
Assmann, W. *et al.* Ionoacoustic characterization of the proton Bragg peak with submillimeter accuracy. *Med. Phys.* **42**, 567–574 (2015)



Jones, K. C., Vander Stappen, F., Sehgal, C. M. & Avery, S. Acoustic time-of-flight for proton range verification in water. *Med. Phys.* **43**, 5213–5224 (2016).

Beam tomography?





Ionacoustics forward modelling

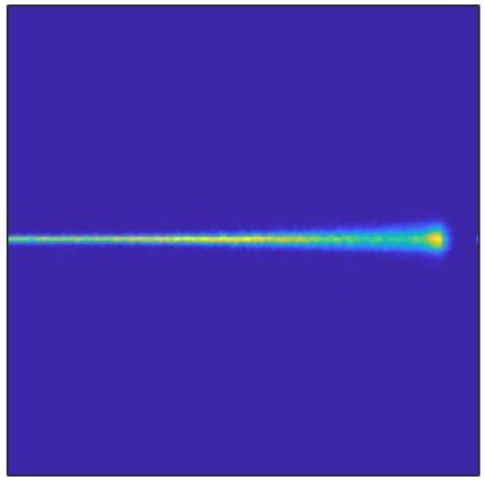
- *Geant4*: compute the volume rate of heat deposition $\mathcal{H}(\mathbf{x}, t)$
- Ionacoustic wave equation for acoustic pressure p:

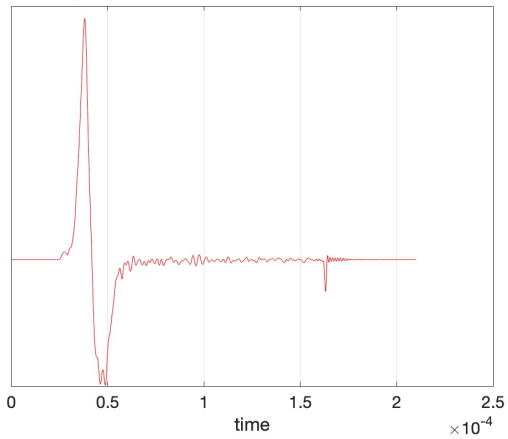
thermal expansion coefficient

$$\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} - \nabla^2 p = \frac{\beta}{C_p}\frac{\partial \mathcal{H}}{\partial t}$$

specific heat capacity

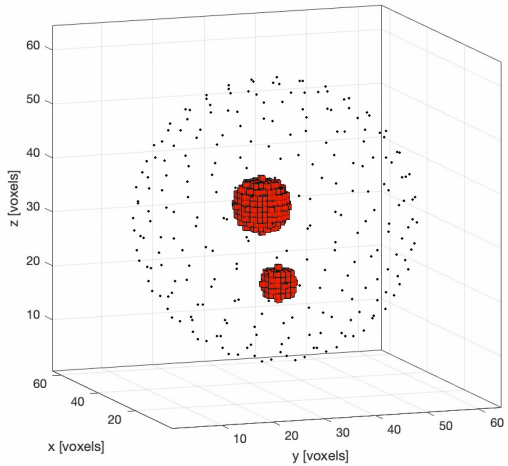
- Broadband simulation using *k-Wave* (www.k-wave.org), software designed for photoacoustics and ultrasound modelling

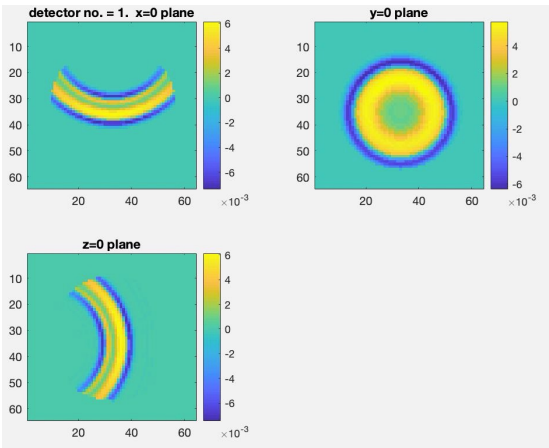




Ionacoustics inverse problem

- Locating the Bragg peak needs just one time series measured on-axis beyond the Bragg peak
- Can we get a quantitative 3D image of the beam (the deposited energy density) given acoustic time series measured at an array of positions around the beam?
- Many image reconstruction methods availablefrom photoacoustics eg. backprojection
- How many detectors can we have?





Risks in using ionacoustics for dosimetry

- Signal-to-noise ratio is too low to detect the acoustic emission
- Acoustic heterogeneities between beam and detector aberrate the measurements
- Number of ultrasound detector array elements is too small to form a useful image
- The image is not quantitatively accurate
- The image reconstruction is too slow to be useful

Ameliorating these risks will require careful and well-informed design of both hardware and software (image reconstruction algorithm).