

# ACOUSTIC AND THERMAL MODELLING OF TRANSCRANIAL ULTRASOUND THERMAL THERAPY

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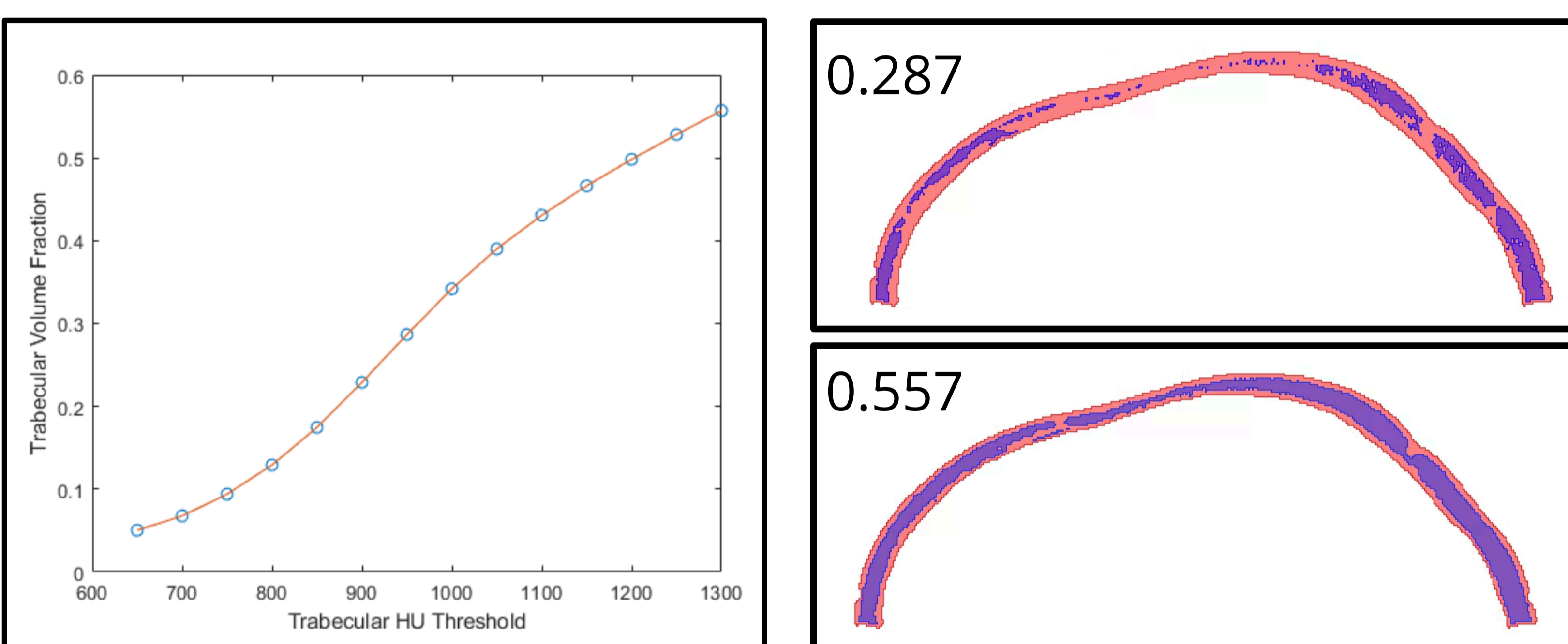
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## BACKGROUND

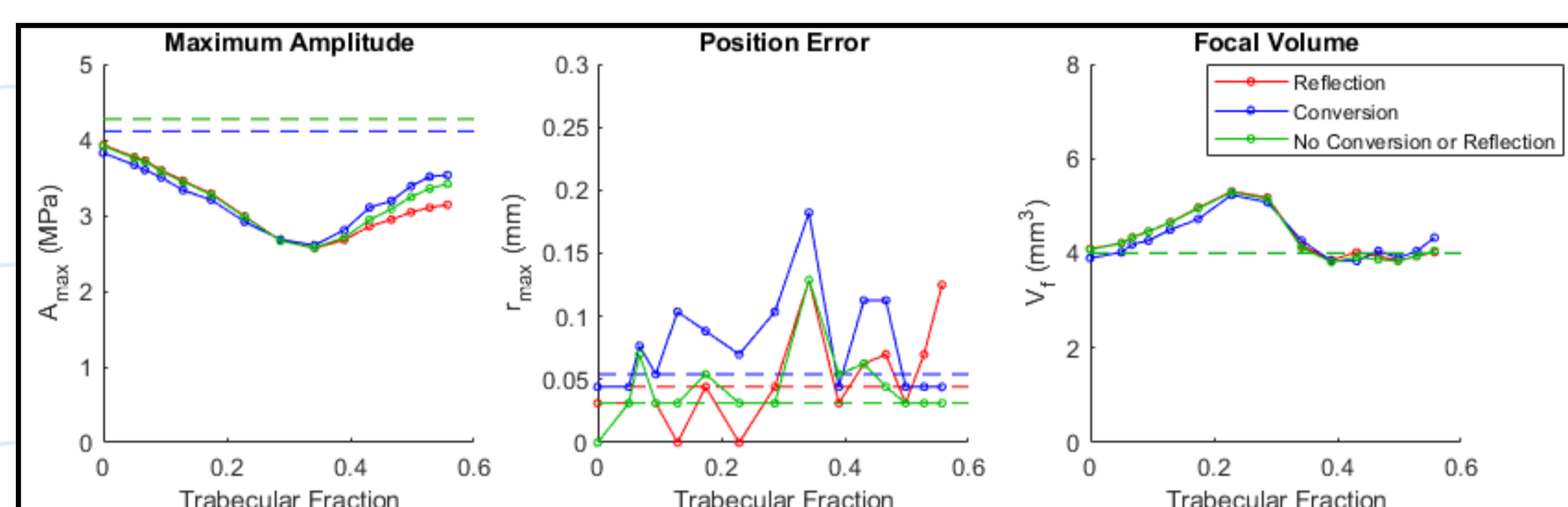
Focused ultrasound has immense potential for treating disorders throughout the brain, but focusing through the skull remains a challenge in clinical applications.

Patient eligibility for transcranial ultrasound treatments is currently based on a ratio of cortical to trabecular thickness, but to date no clear justification of this metric has been provided in terms of the physics of ultrasound propagation.

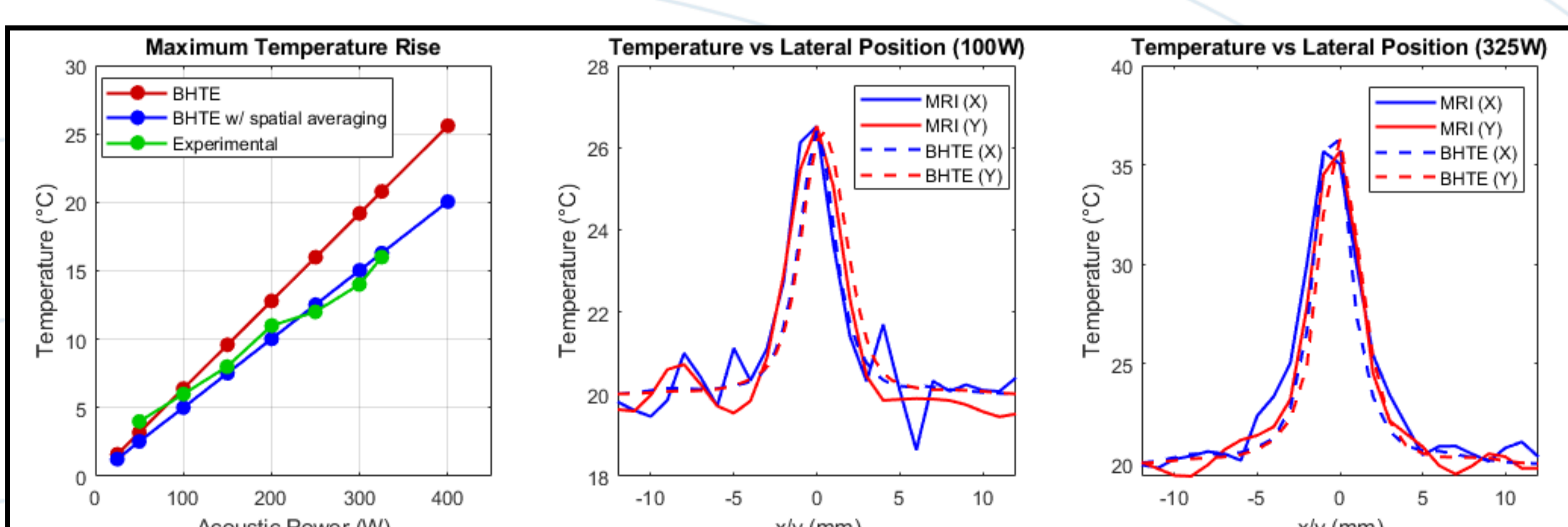
This work presents numerical modelling of intra-cranial acoustic and thermal fields, and quantifies the effect of model complexity on clinically relevant parameters.



**FIGURE 1:** (left) Variation of trabecular bone volume relative to total skull volume with the upper HU threshold used for generation of trabecular bone layer. (Right) 2 different skull models with corresponding trabecular volume fraction inset.



**Figure 2:** Simulation results showing the maximum amplitude (left), position error (center), and focal volume obtained from simulations that include internal reflection (red), shear wave mode conversion (blue), or neither (green). Dashed lines denote results obtained for a homogeneous skull model.



**Figure 3:** (right) Simulated and experimental maximum temperature rise as a function of total acoustic power obtained. Temperature as a function of lateral position for 100W (centre) and 325W (right) obtained using MR thermography (solid line) and numerical simulations (dashed lines).

## METHODS

Ray-tracing simulations of transcranial FUS with the ExAblate INSIGHTEC Neuro clinical system were performed using the CIVA Healthcare simulation platform. 3D models of cortical and trabecular layers were generated using CT data of human skull samples. The relative volume of trabecular bone was adjusted by varying the Hounsfield threshold used to generate the trabecular layer, as shown in Figure 1.

Simulations that included mode conversion and internal reflection were compared with those that neglected these effects. Focal quality was quantified using the maximum amplitude, error in focal position, and focal volume.

Simulated acoustic fields were combined with the a numerical thermal model to predict temperature rise at the focus, which was compared to experimental temperature rise measured using MR thermometry.

## RESULTS

Figure 2 illustrates the effect of reflection and mode conversion on simulated transcranial focal quality compared to simulations that neglect these effect.

The effects of shear wave mode conversion was significantly greater than internal reflection. Degraded focal quality with increasing levels of trabecular bone persists regardless of mode conversion or internal reflection.

Simulated and experimental temperature rise as a function of acoustic power is shown in Figure 3, as well as the spatial temperature field. Simulations demonstrated good agreement with experimentally measured temperatures across a range of acoustic power levels.

## CONCLUSIONS

This work quantifies the importance of various acoustic wave behaviour and skull heterogeneity in transcranial focused ultrasound modelling. Good agreement of simulated temperature rise indicates that the CIVA Healthcare platform provides rapid and accurate prediction of temperature rise.

## ACKNOWLEDGEMENTS

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# NUMERICAL MODELLING FOR THERAPEUTIC FOCUSED ULTRASOUND

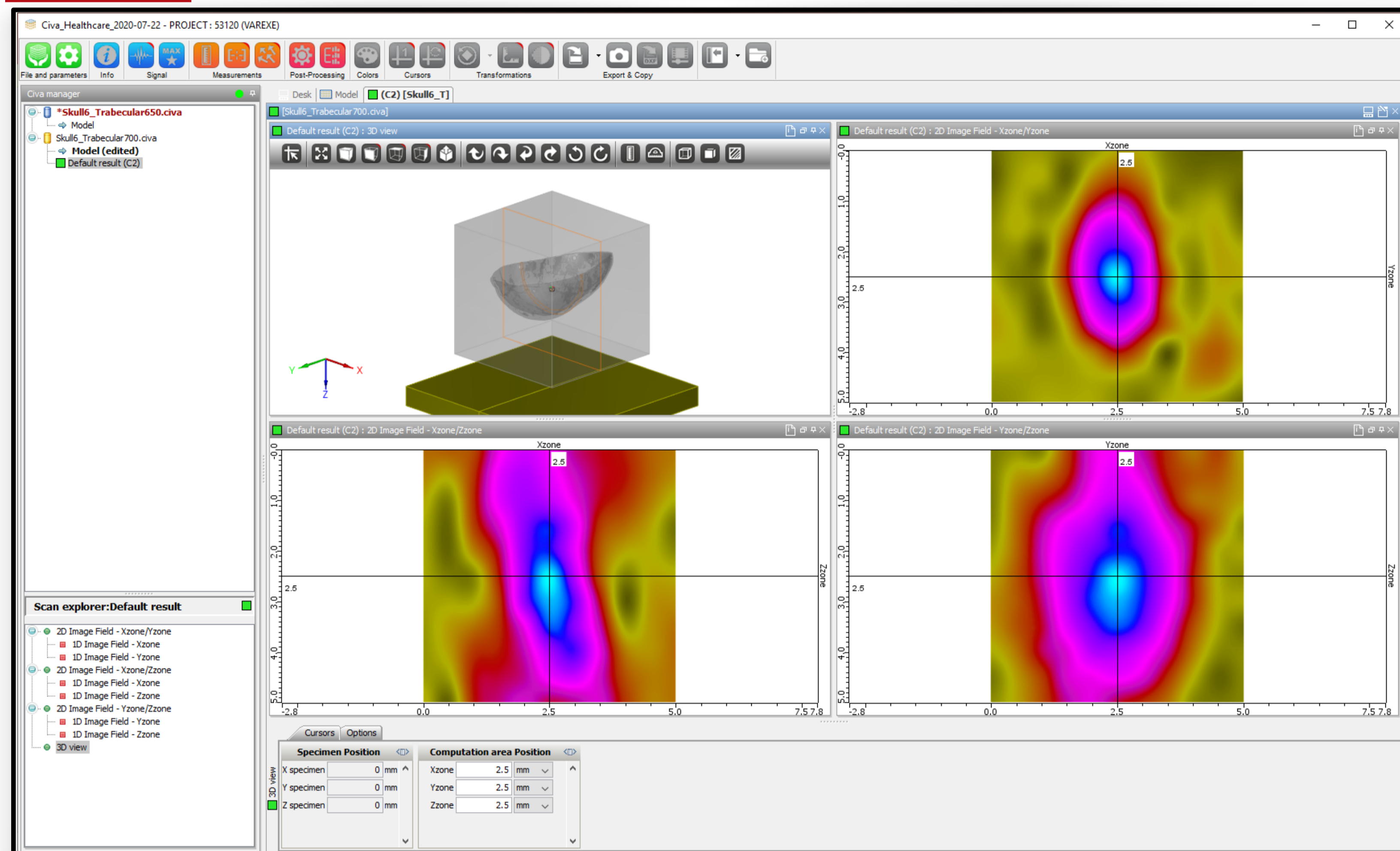
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## NUMERICAL SIMULATION TOOLS



### CIVA Healthcare Simulation Platform



- Platform for the simulation of acoustic fields using ray-tracing model, with coupled numerical BHTe model.
- Open platform allowing integration of user modules.
- Custom tissue and transducer modelling

### k-Wave MatLab Toolbox



**k-Wave**

A MATLAB toolbox for the time-domain simulation of acoustic wave fields

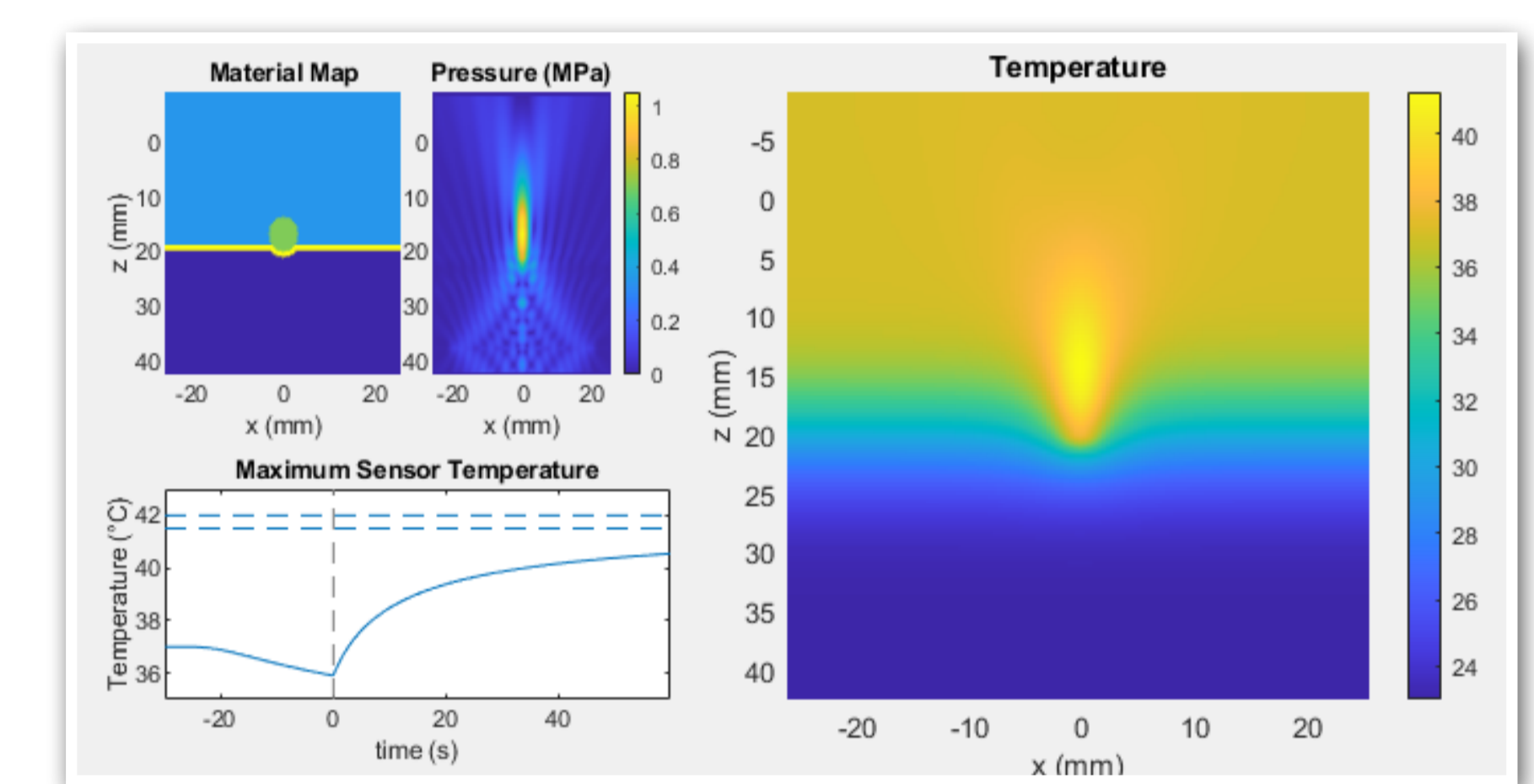
- Open source acoustic toolbox for MATLAB and C++.
- Advanced full wave time-domain including nonlinear propagation, heterogeneous media, power law absorption.

### Virieux Full Wave Acoustic Model

- Custom built full wave time-domain FDTD model including nonlinear propagation, heterogeneous media.
- Models develop in MatLab and C++ with CUDA GPU.

### Finite Difference Bioheat Transfer Equation Solver

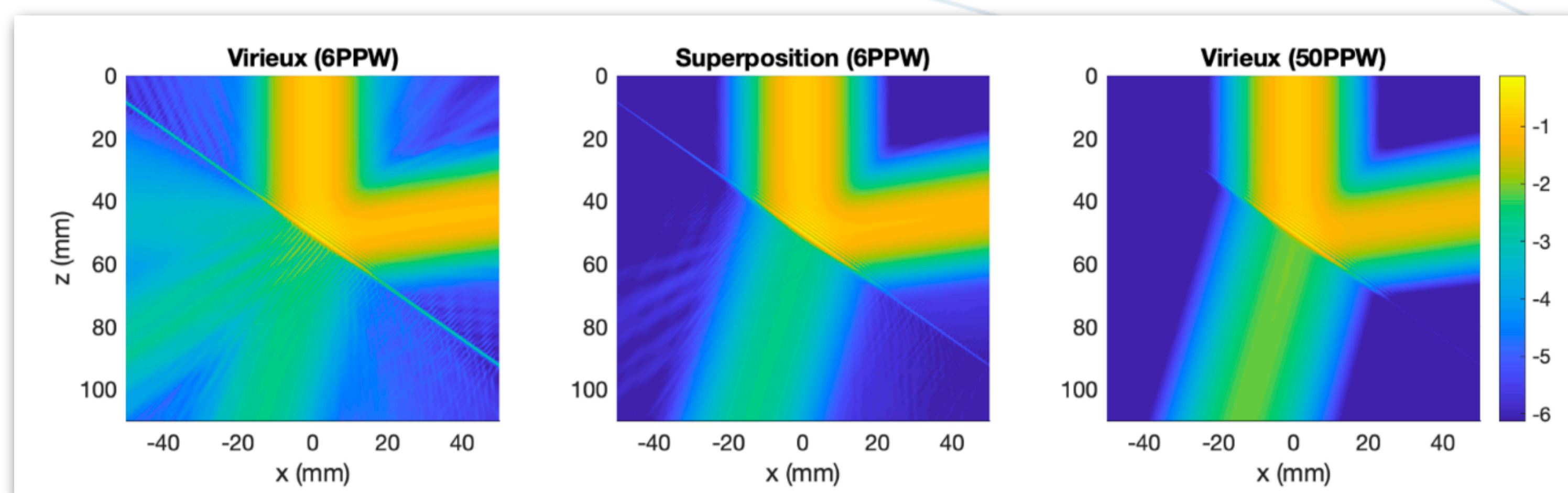
- Custom-built versatile finite difference temperature model.
- Coupled with k-Wave, Virieux finite difference model, and CIVA Healthcare Platform.



## FEATURED WORK

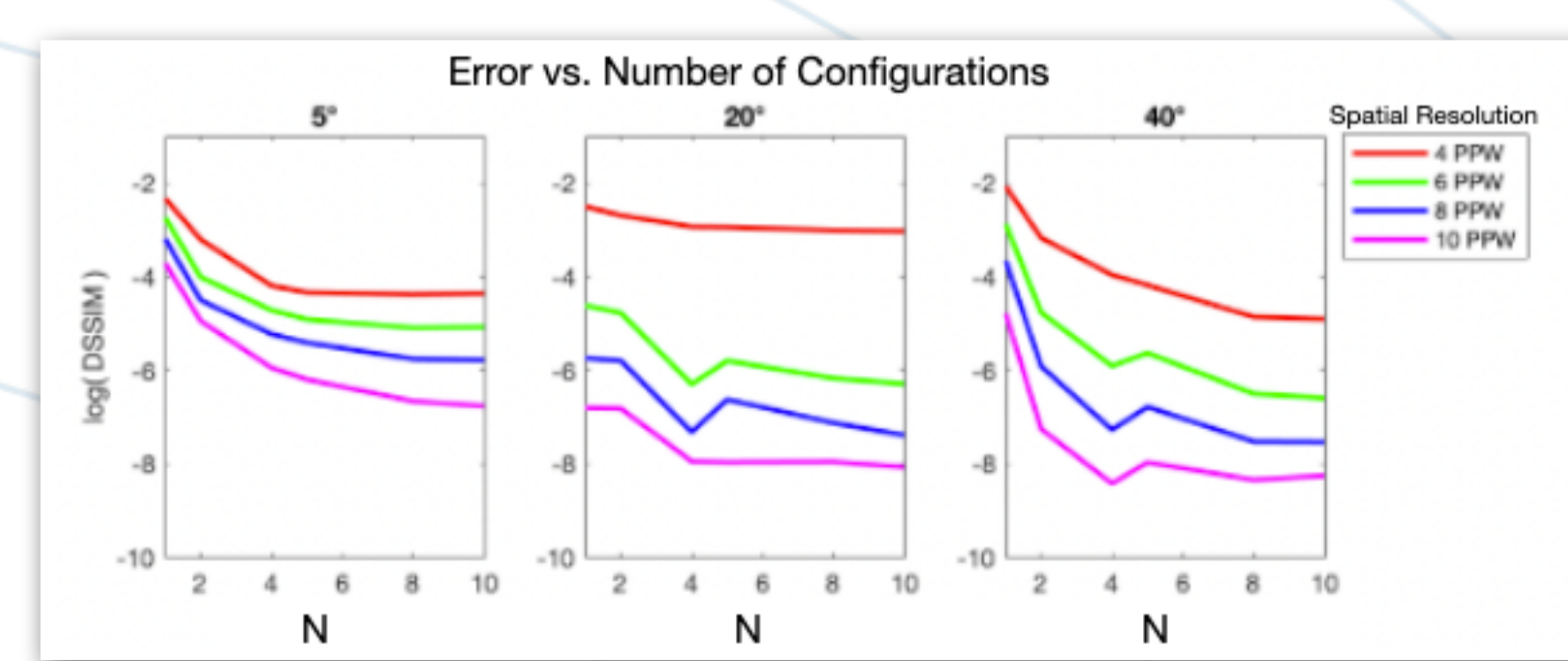
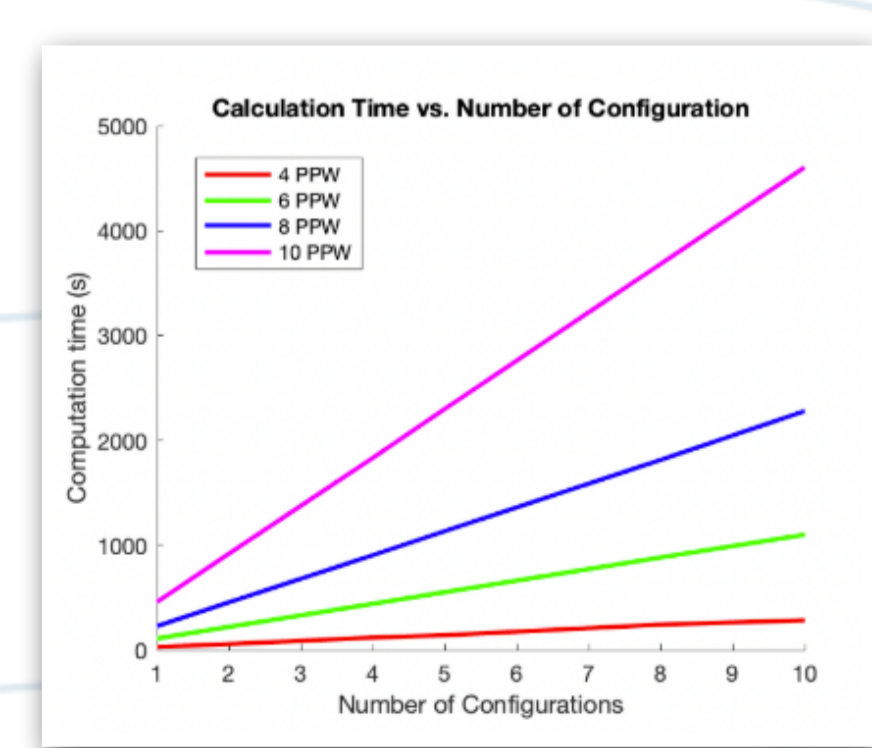
### Superposition method for modelling boundaries between media in viscoelastic finite difference time domain simulations

- Development of mathematical algorithm combining multiple simulations to reduce errors in full-wave acoustic simulations.
- Featured JASA Technical Highlight 2019.



### Application of the Superposition Method with k-wave pseudo-spectral modelling (2020)

- Implementation and validation of superposition method within the k-wave acoustic model.



### REFERENCES

Treeby et. al. (2010). *J. Biomed. Opt.*, 15(2),  
Virieux (1986). *Geophysics*, 51(4)  
Drainville et. al. (2019). *J. Acoust. Soc. Am.*, 146(6)

### Evaluation of Pseudorandom Sonications for Reducing Cavitation With a Clinical Neurosurgery HIFU Device (2021)

- Use of gated sonication pulses to reduce threshold of cavitation for transcranial focused ultrasound.
- Application of nonlinear full wave acoustic modelling (k-wave) for validation of experimental results.

### A viscoelastic model for the prediction of transcranial ultrasound propagation: Application for the estimation of shear acoustic properties in the human skull (2017)

- Development, optimization, and application of numerical modelling for estimation of skull acoustic properties.

### Acoustic and Thermal Modelling of Transcranial Ultrasound Thermal Therapy (in progress)

- Simulation study examining the effect of skull property uncertainty and heterogeneity on transcranial focalization.

Lafon et. al. (2021). *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*,  
Pichardo et. al (2017). *Phys. Med. Biol.*, 62(17)  
Drainville & Pichardo (2020). 2020 IEEE Int Ultrasonics Symp