# A novel array processing method for precise depth detection of ultrasound point scatter

***Konstantinos Diamantis[1]***,

*Paul A. Dalgarno[1], Alan H. Greenaway[1], Tom Anderson[2], Jørgen A. Jensen[3] and Vassilis Sboros[1]*

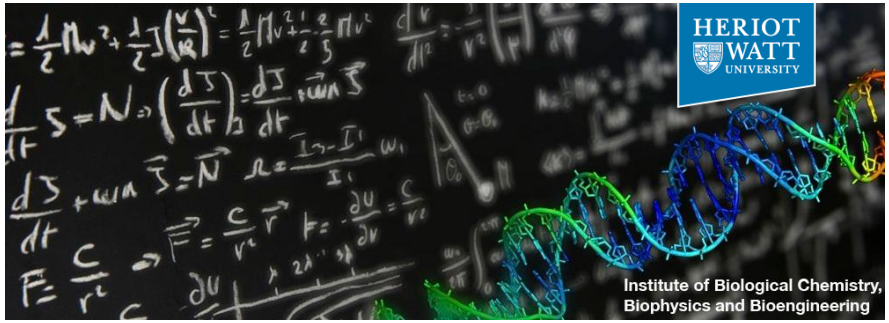
*[1]Heriot-Watt University Edinburgh, UK*

*[2]University of Edinburgh, UK*

*[3]Technical University of Denmark*

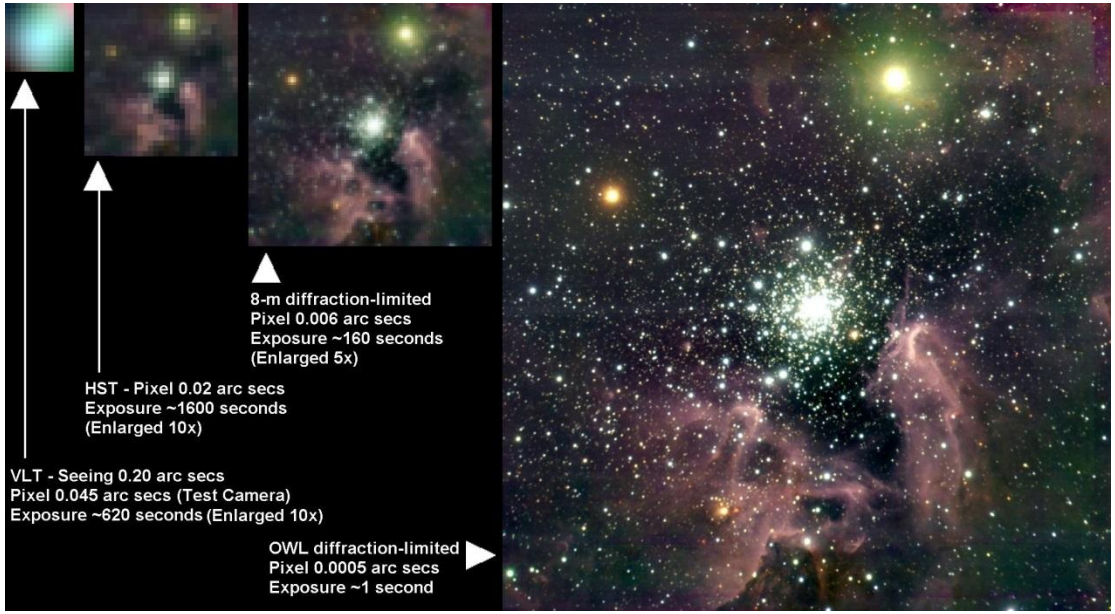
Center for Fast Ultrasound Imaging

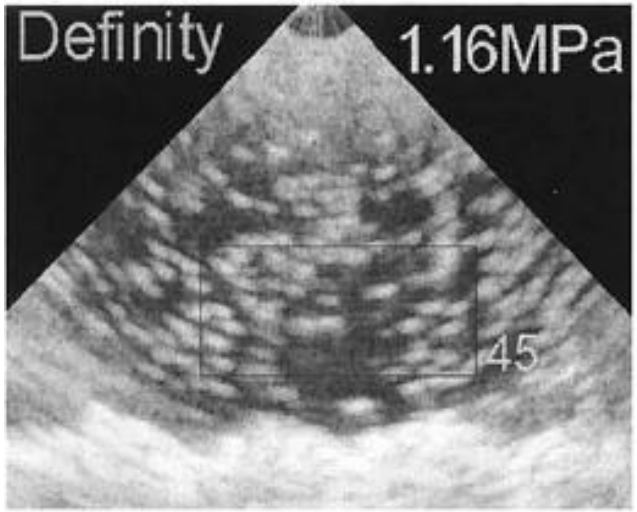
Department of Electrical Engineering



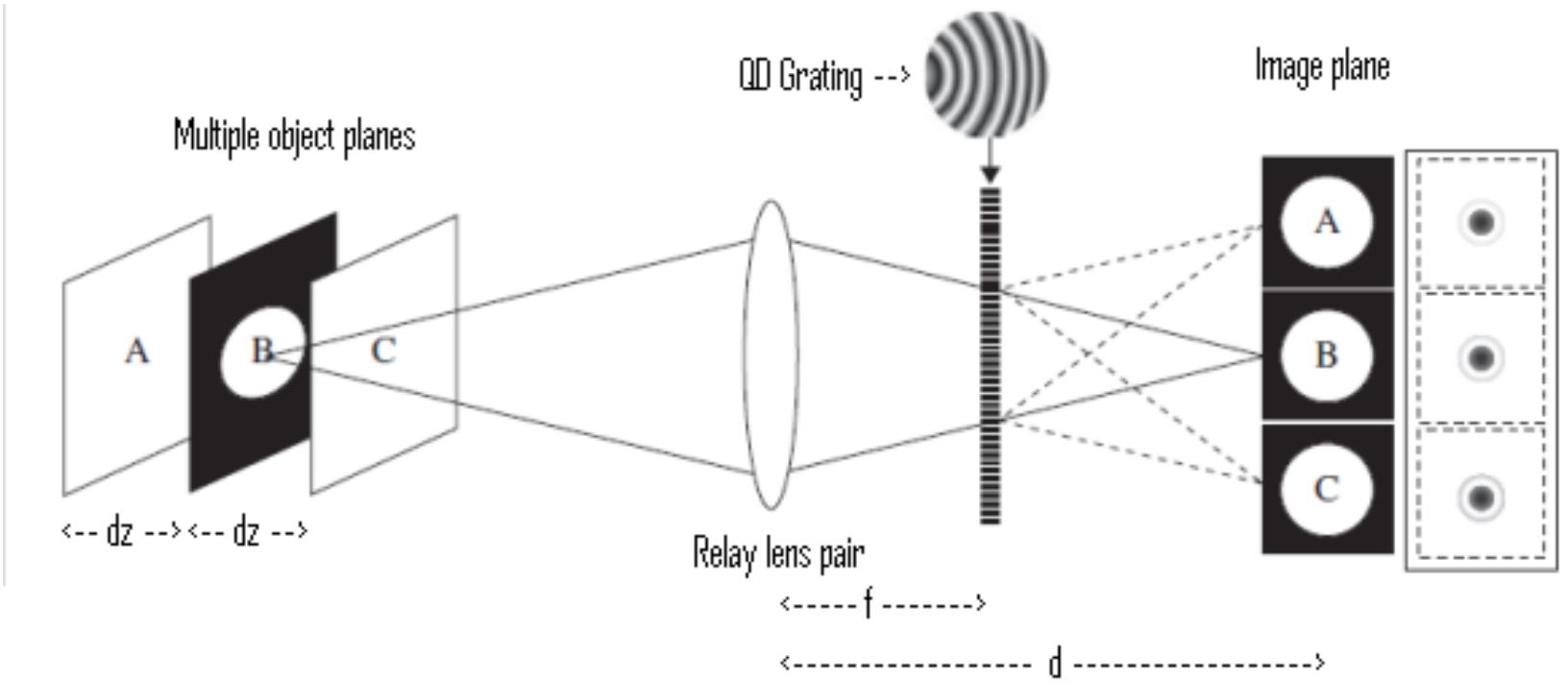
# Background

- Point source aberrations have been studied extensively in astronomy, optical microscopy, etc.
- Information that increases depth resolution can be extracted.



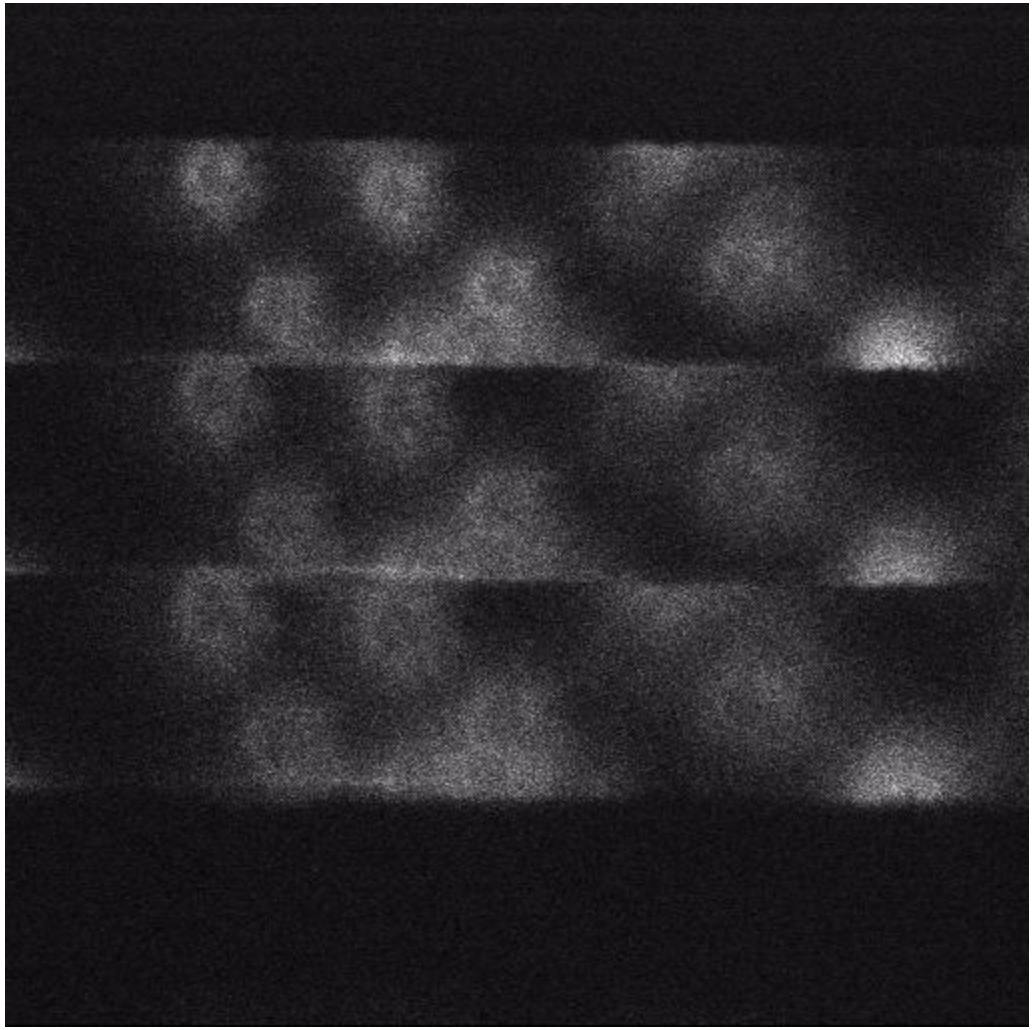



# Optical System




*P. M. Blanchard, A. H. Greenaway, "Simultaneous multi-plane imaging with a distorted diffraction grating", OSA, Applied Optics, vol. 38, no. 32, pp. 6692-6699,1999.*

# Multi-Plane Imaging



- Fluorescent particles with a diameter of 200 nm mounted on precision translation stage.

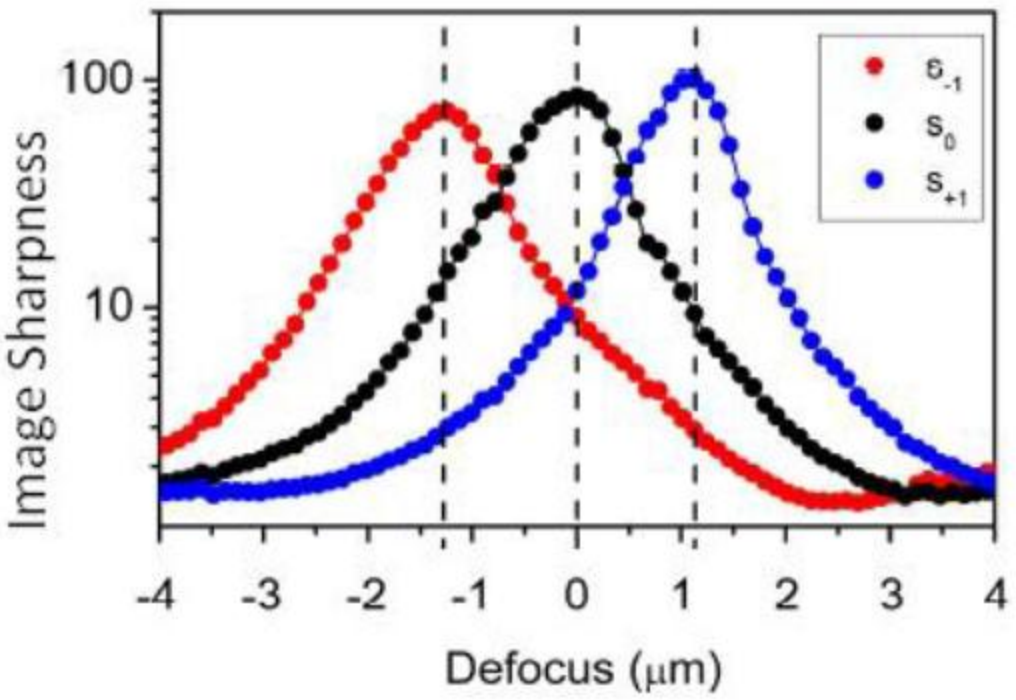
0.63x0.63mm$^2$

- Three simultaneous images are acquired for each position of the translation stage that is then moved to the next position.

# Normalized Image Sharpness

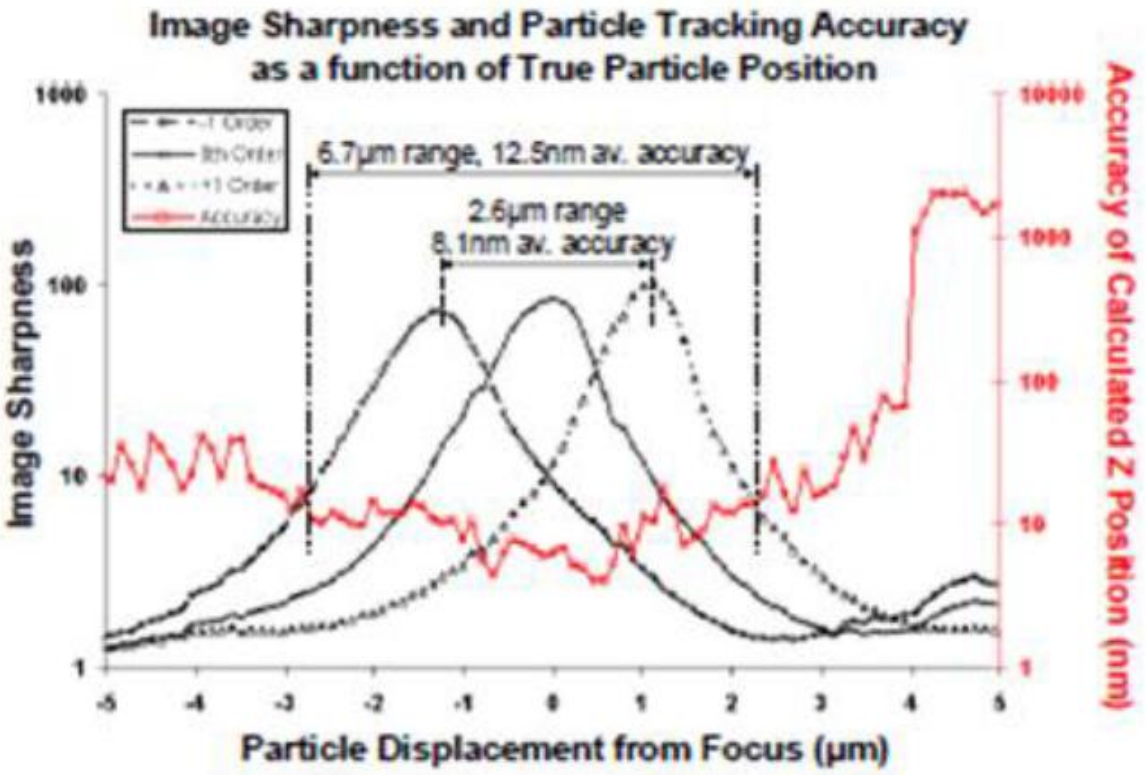
Extracted from a small window including only one particle by:

$$S = \sum_{k=1}^{q} (n_k^2 - n_k) \Big/ \left( \sum_{k=1}^{q} n_k \right)^2$$




and combined with Maximum Likelihood Estimation (MLE) results in...

# Accuracy

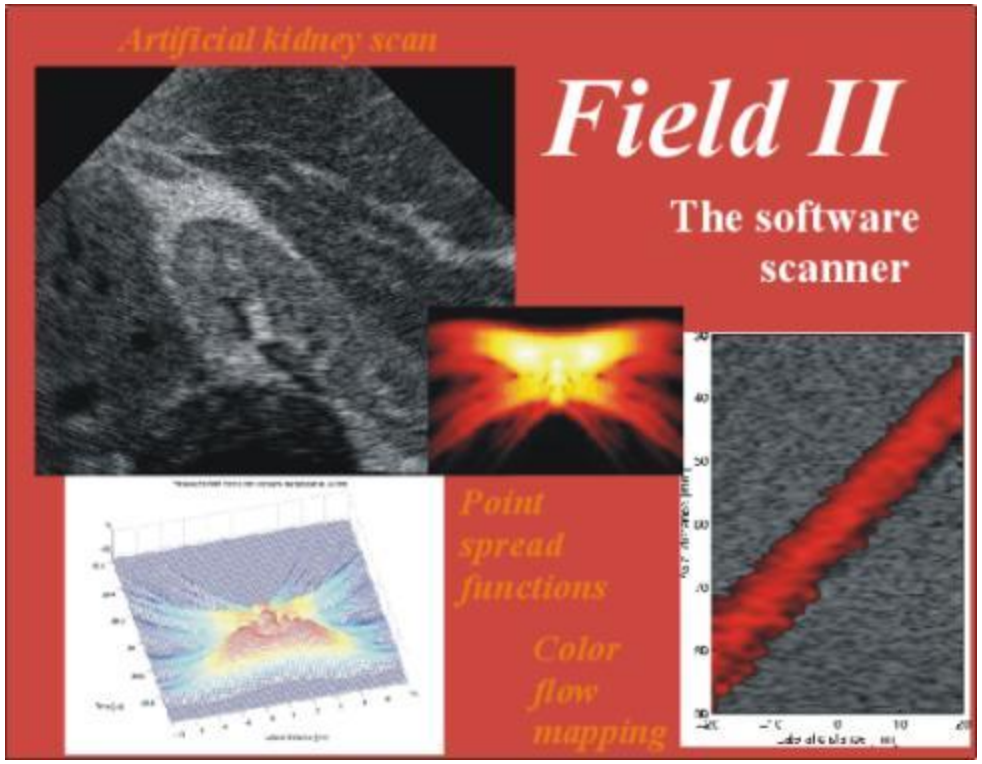



$(\lambda = 500nm)$

*H. I. C. Dalgarno, P. A. Dalgarno, A. C. Dada, C. E. Towers, G. J. Gibson, R. M. Parton, I. Davis, R. J. Warburton and A. H. Greenaway, "Nano-metric depth resolution from multi-focal images in microscopy", J. R. Soc. Interface, vol.8, no. 60, pp. 942-951, January 2011.*

# Ultrasound simulation

- Transducer definition
- Moving point target



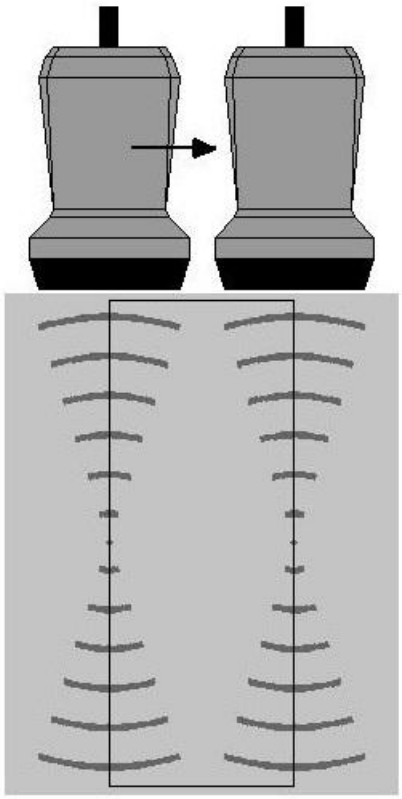

- Ultrasound transmission
- Multiple receive foci
- Noise addition

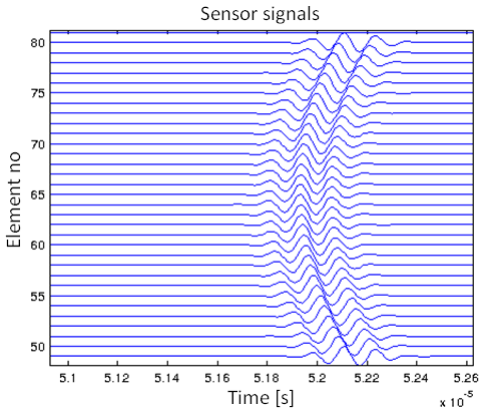
Jensen, J. A., "Field: A program for simulating ultrasound systems," Med. Biol. Eng. Comp., 10th Nordic-Baltic Conference on Biomedical Imaging, Vol. 4, Supplement 1, Part 1, 351–353 (1996).

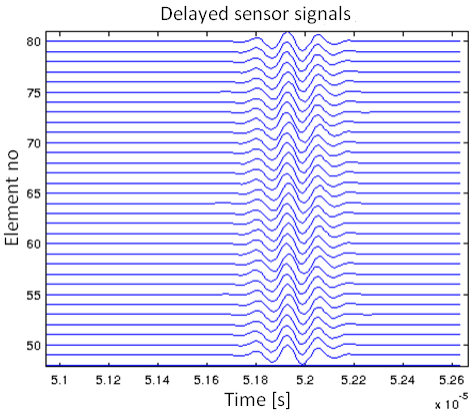
Jensen, J. A. and Svendsen, N. B., "Calculation of pressure fields from arbitrarily shaped, apodized, and excited ultrasound transducers," IEEE Trans. Ultrason., Ferroelec., Freq. Contr. 39, 262–267 (1992).

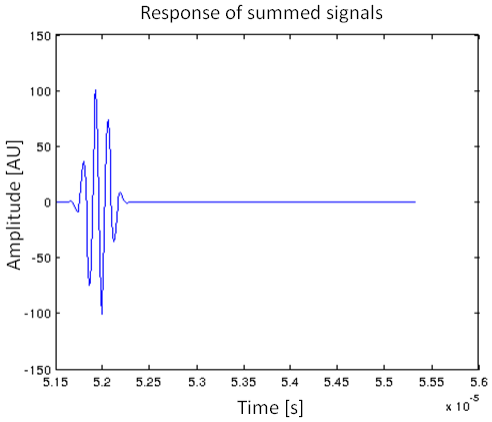
# Transmit & receive processing

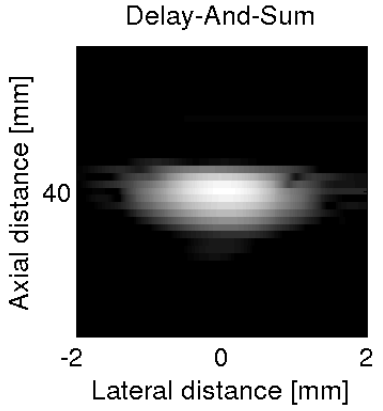
- Transmit focus can be set only once during each acquisition
- Offline beamforming with multiple foci in receive





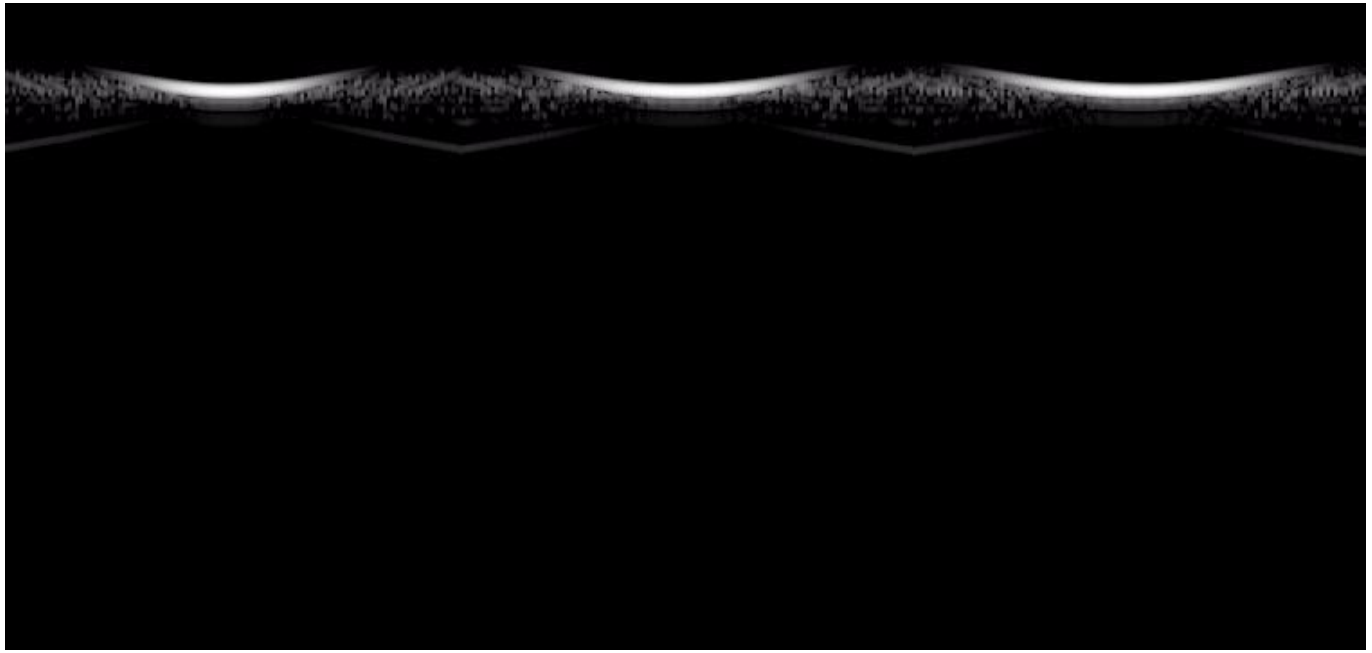



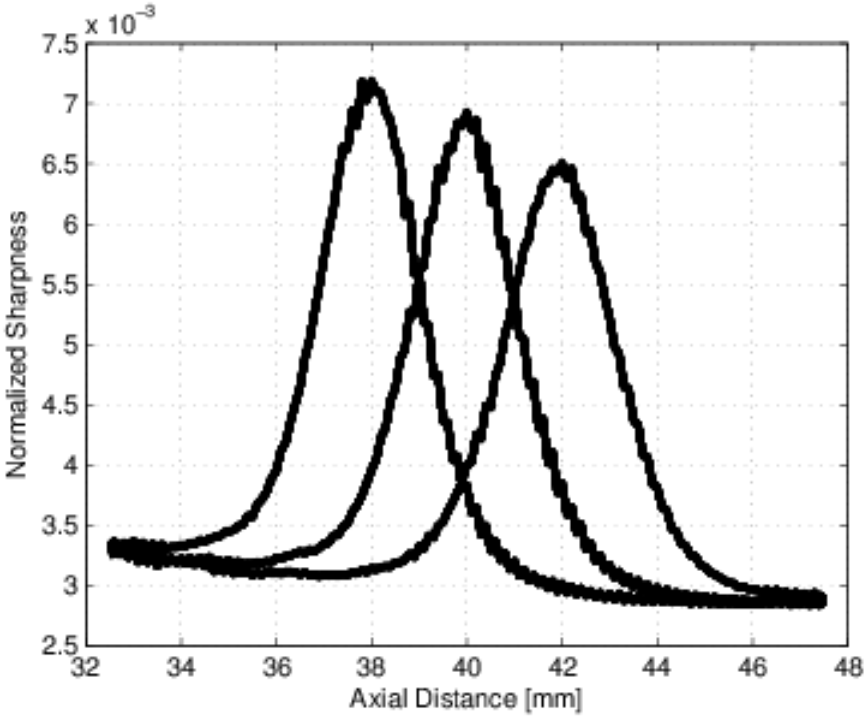
# Ultrasound simulation

- Beamformed responses of a moving point target.
- Three different receive foci (with 2 mm distance).
- Dimensions are 14x20 $mm^2$ for each image plane.

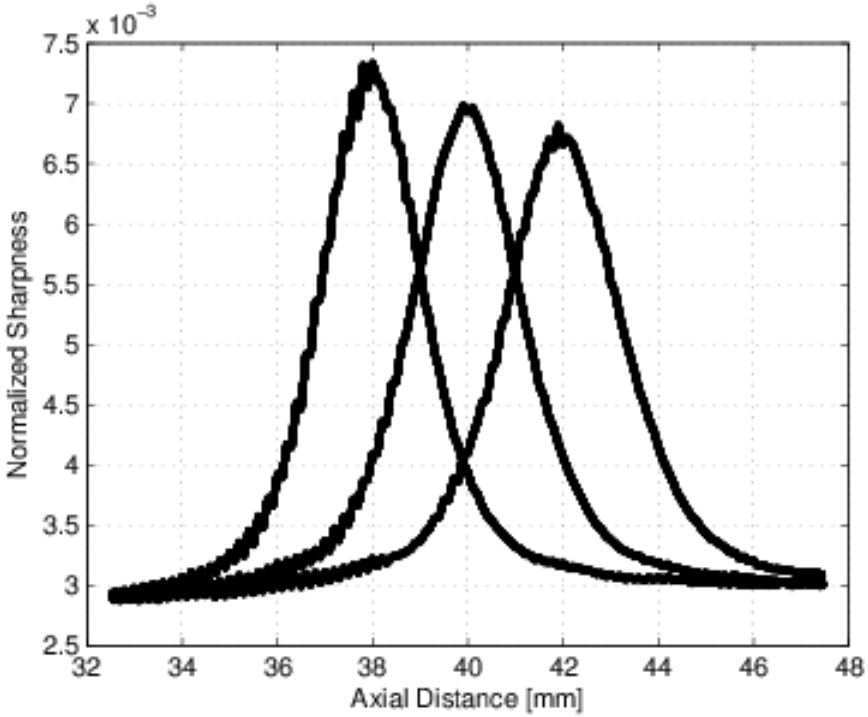


# Normalized Ultrasound Sharpness

Transmit focus at 30 mm



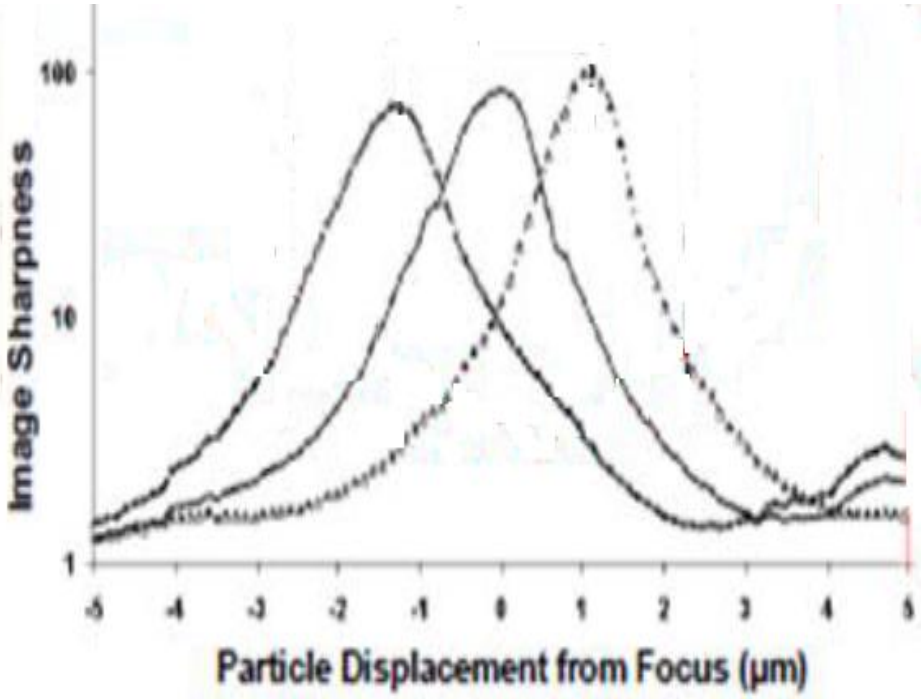

Transmit focus at 50 mm



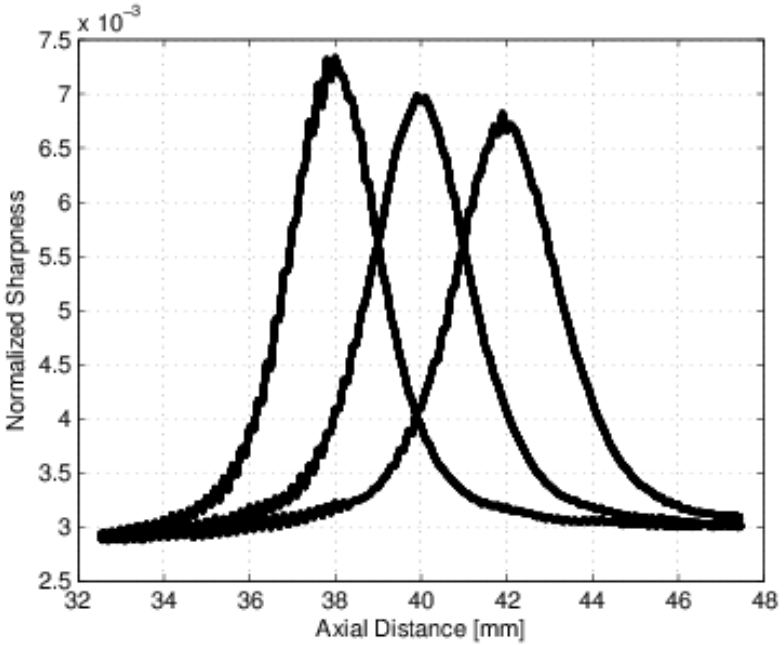

- Extracted by signal amplitudes: $S = \sum_{k=1}^{q} A_k^4 / (\sum_{k=1}^{q} A_k^2)^2$

# Normalized Sharpness

Biological Microscopy



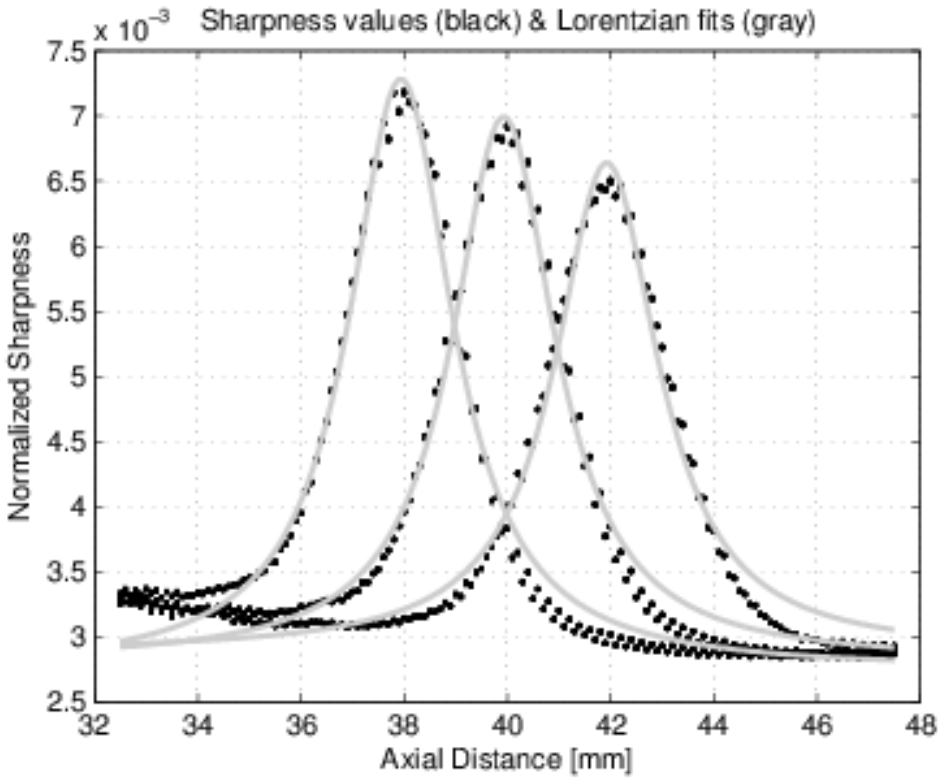

Ultrasound




Institute of Biological Chemistry, Biophysics and Bioengineering
Heriot-Watt University, Edinburgh

Center for Fast Ultrasound Imaging
Technical University of Denmark

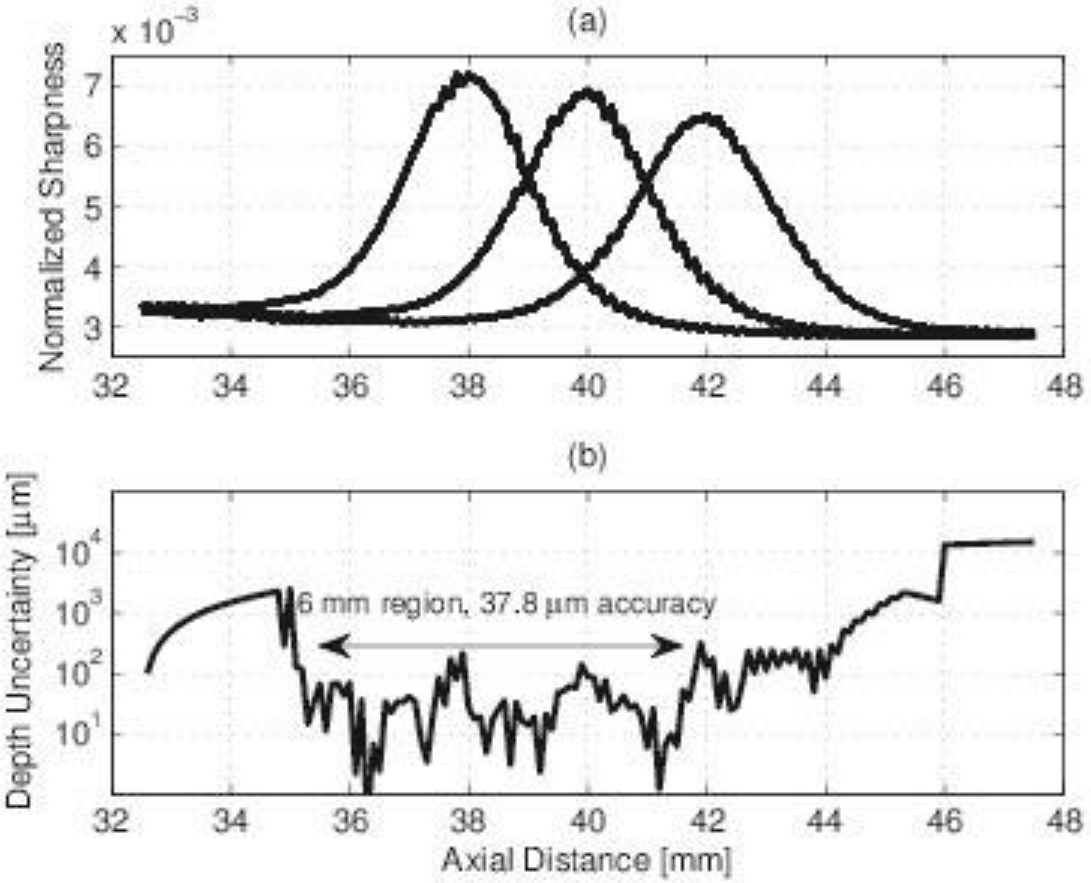
# Maximum Likelihood Estimation




- Repetitive measurements: due to noise sharpness curves are not identical
- General curve shape maintained as in optics; similar PDF selected

PDF model: $$P(s_j \mid z) = \frac{e^{\bar{S}_j^2}\,\bar{S}_j^{\alpha-1}(z)\beta^{-\alpha}}{\Gamma(\alpha)}, \quad \alpha = \frac{\bar{S}_j^2(z)}{\bar{\sigma}_j^2} \quad \text{and} \quad \beta = \frac{\bar{\sigma}_j^2}{\bar{S}_j^2(z)}$$

# Accuracy with shorter transmit focus

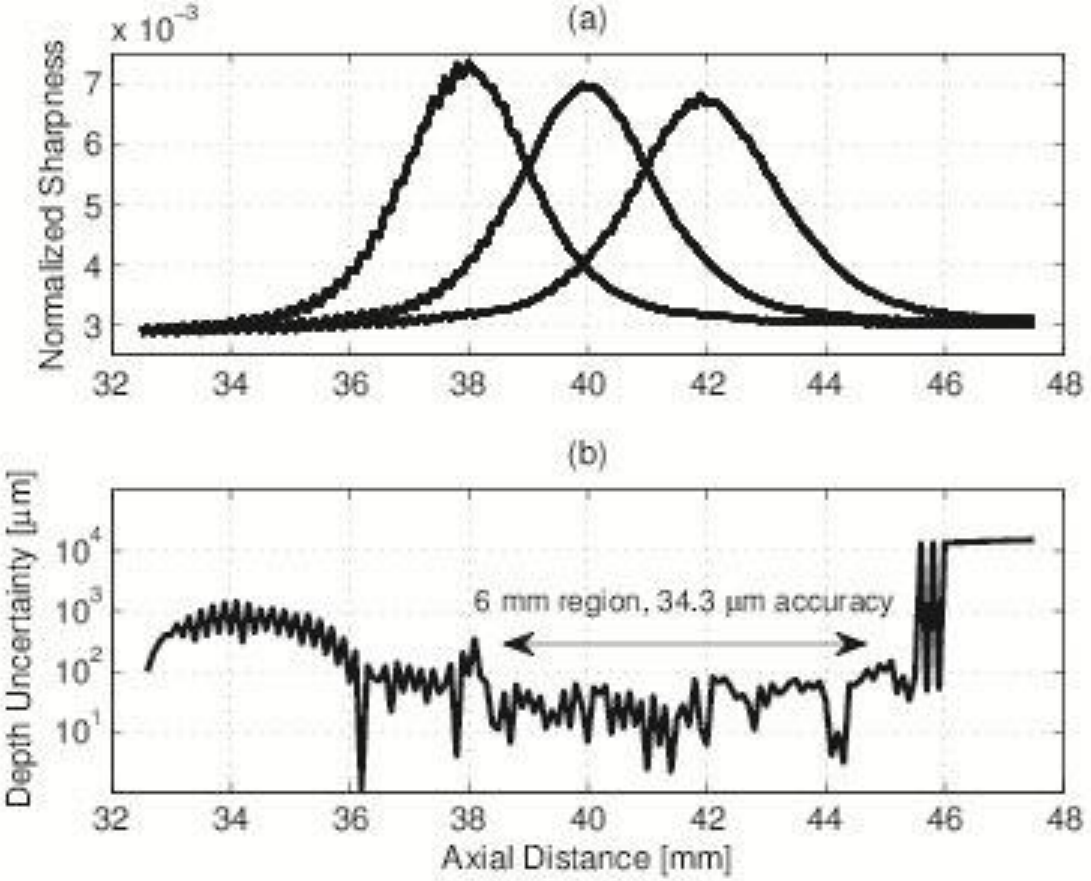



$(\lambda = 220\mu m)$

Institute of Biological Chemistry, Biophysics and Bioengineering
Heriot-Watt University, Edinburgh

Center for Fast Ultrasound Imaging
Technical University of Denmark

# Accuracy with longer transmit focus



# Conclusion

• An ultrasound method originating from biological microscopy has been presented.

•Three or more simultaneous sharpness values can be extracted for each depth position of a moving target.

• Image sharpness based algorithm may reach down to $\lambda / 6$ axial resolution.

• Further investigation and experimental validation are needed before being suitable for real-time applications.

# Acknowledgments

This work was financially supported by Heriot-Watt University (Edinburgh, UK), by grant 024-2008-3 from the Danish Advanced Technology Foundation, and by BK Medical Aps, (BK Medical ApS, Herlev, Denmark).

**Thank you for your attention!**