A novel dual-sensor approach for the determination of cavitation *in-vitro*

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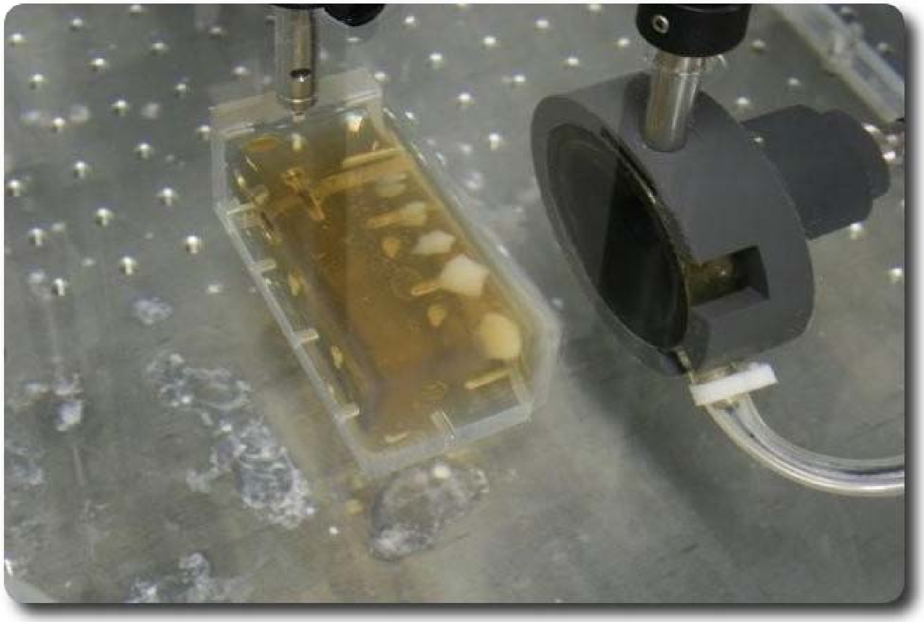
Project background

Sonic Concepts HIFU transducers

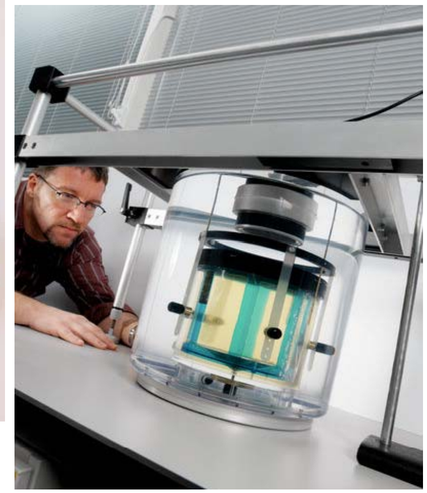


Courtesy of BUBL, Oxford, UK

High Intensity Focused/Therapeutic Ultrasound (HIFU, or HITU) fields require calibration to underpin effective application and treatment, but present significant measurement challenges due to secondary effects: standards are under development

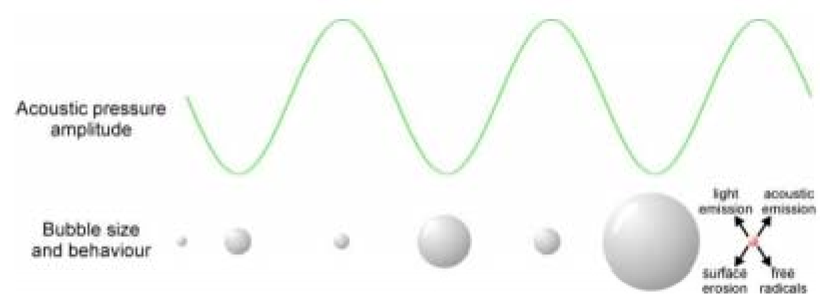
Measurement parameters

- Acoustic pressure → acoustic intensities
- Acoustic power
- ➢ *Measurement methods available*



❖ <u>But other effects are important…</u>

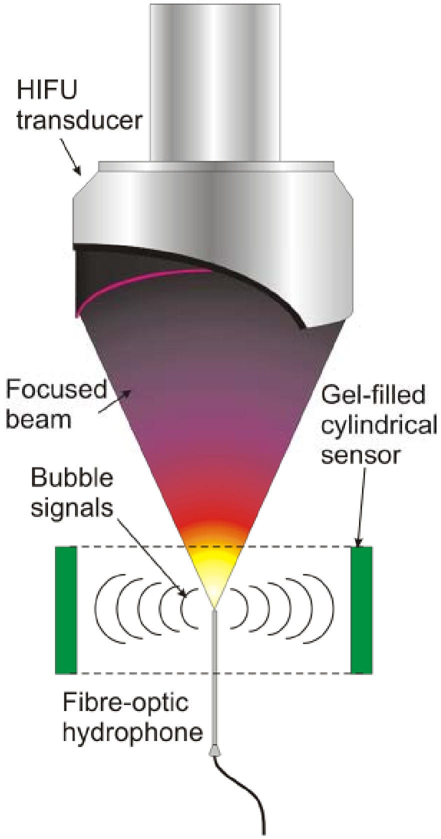
- Streaming?
- Thermal effects?
- Acoustic cavitation →



Feasibility project aims

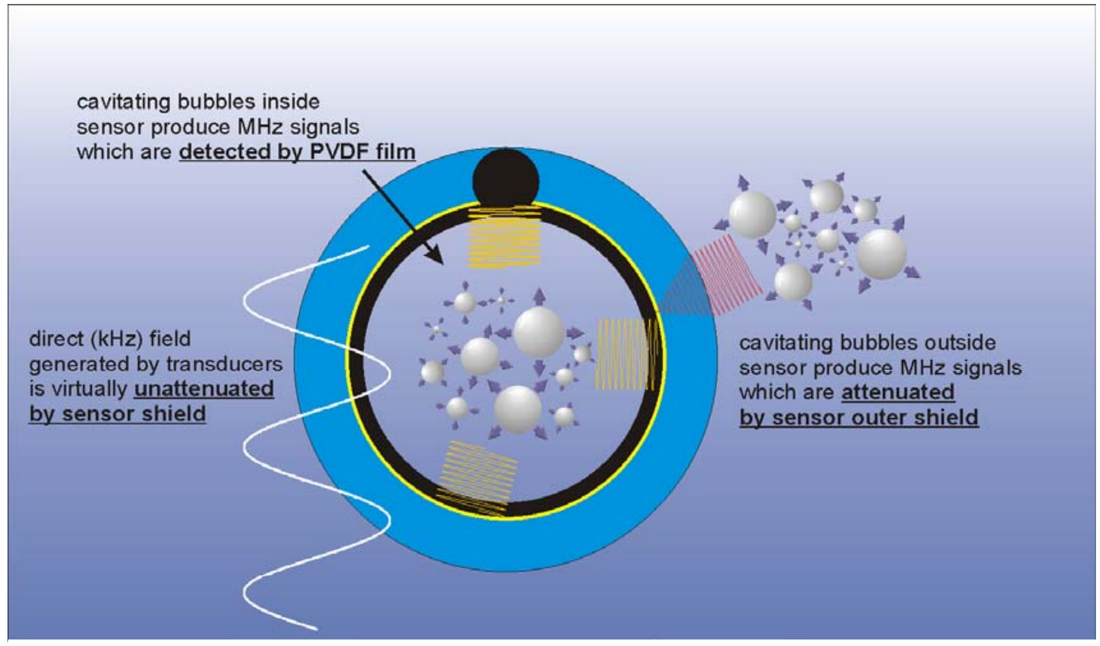
To develop and apply a new combination of measurement techniques for detecting and characterising acoustic cavitation in tissue-like media

- Design and manufacture HIFU Cavitation sensor
- Design and manufacture test configuration
- Investigate dual use of new sensor and fibre-optic hydrophone
- Identify cavitational characteristics of tissue-like media as a function of applied acoustic pressure



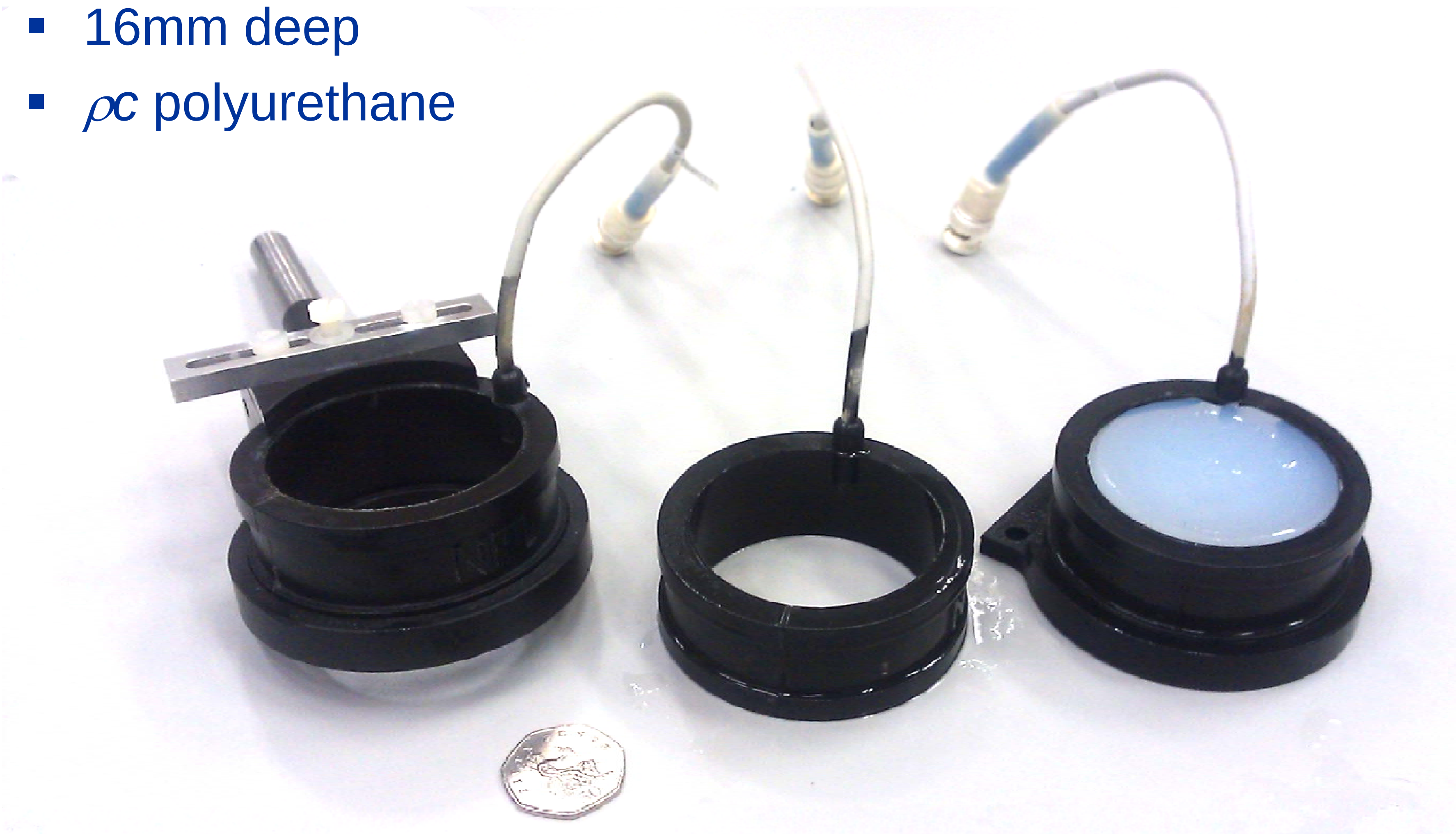
NPL Cavitation Sensor

- Designed originally for use in kHz-frequency systems
- Passive detection of broadband acoustic emissions from multi-bubble cavitation
- Utilises PVDF film and bespoke polyurethanes which provide spatially sensitive measurements of cavitation activity



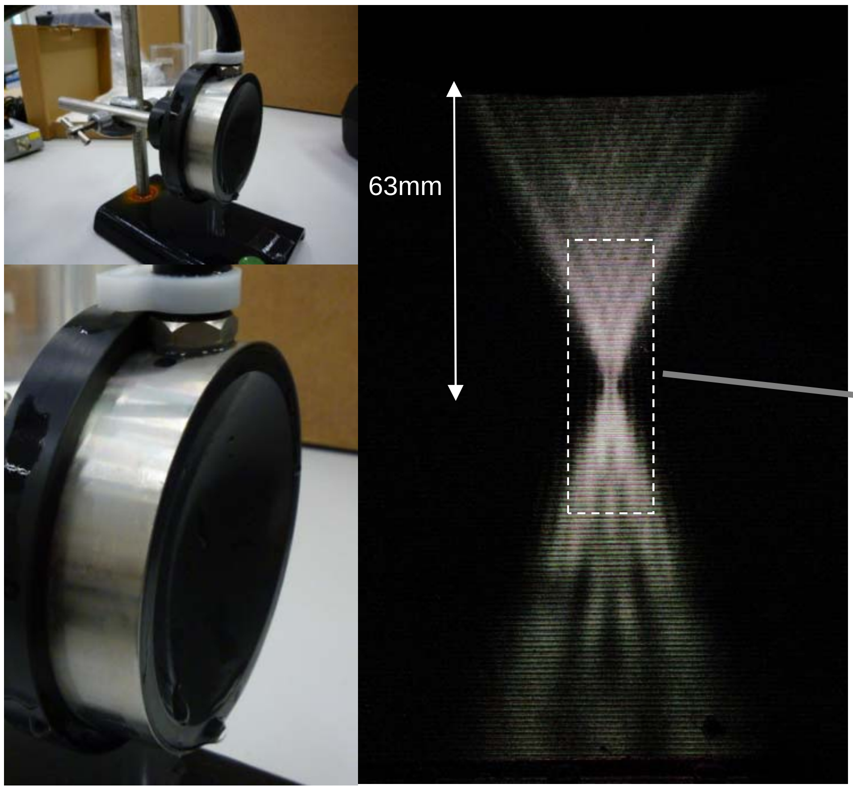
NPL HIFU Cavitation sensor

- 65mm diameter
- 16mm deep
- ρc polyurethane

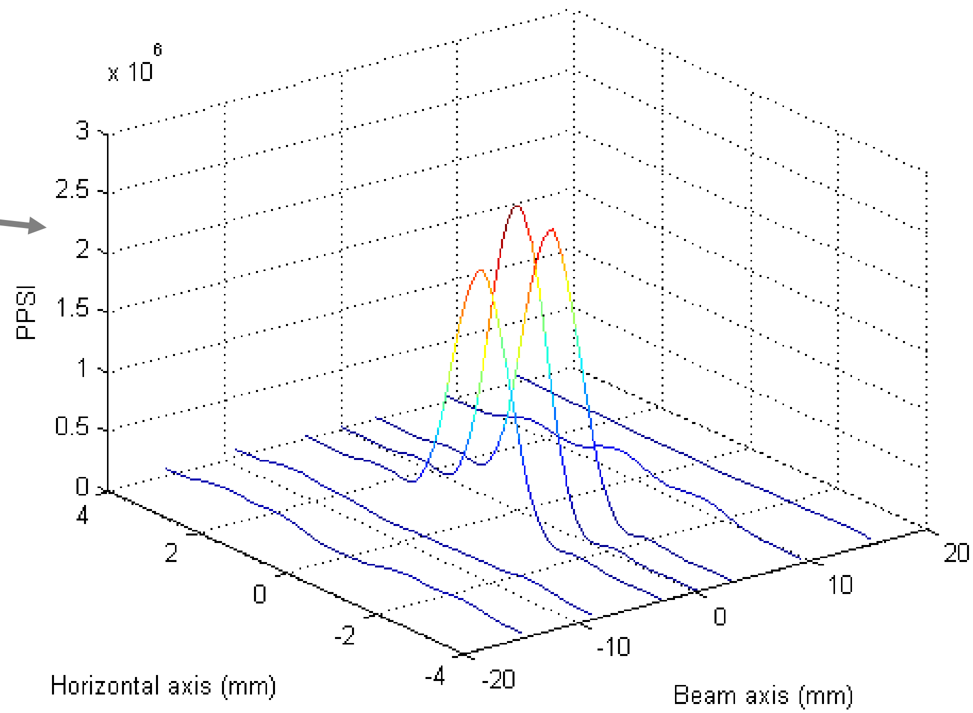


The HIFU field – in water

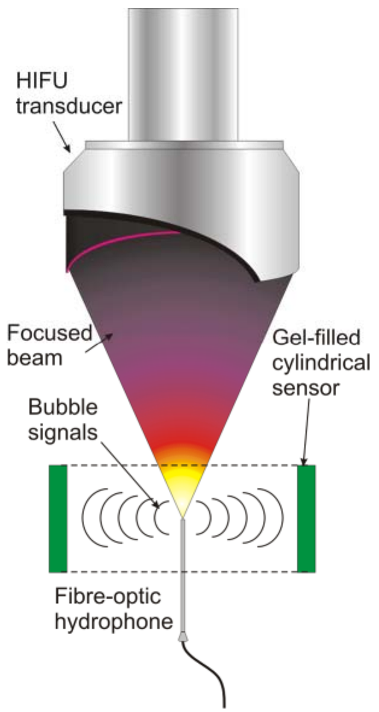
Sonic Concepts 1.1 MHz

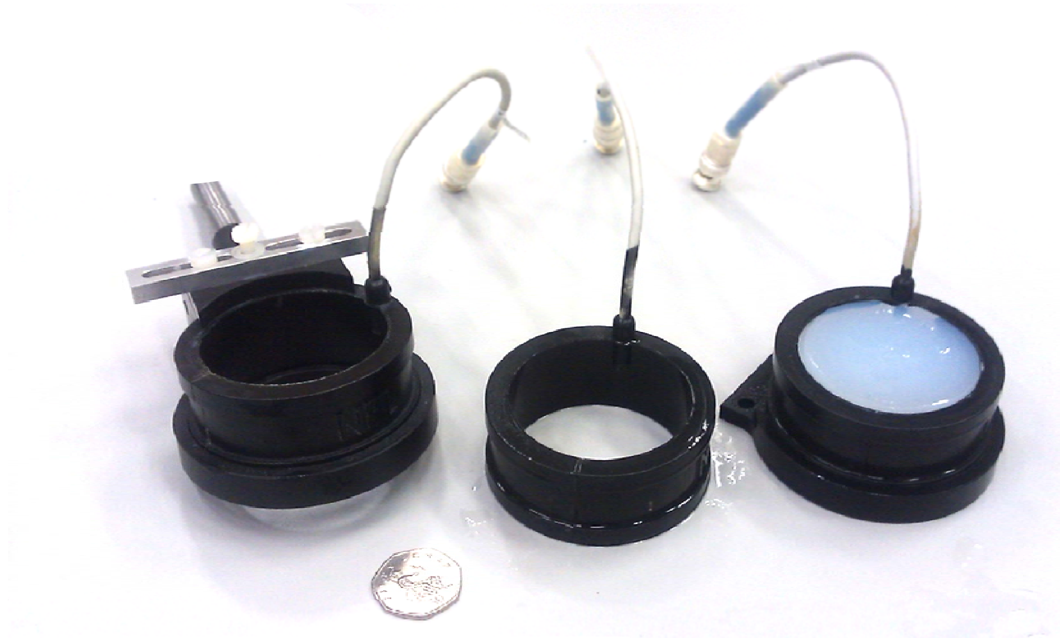


Pulse-pressure-squared integral around focus of Sonic Concepts 1.1 MHz transducer, using Onda Golden Lipstick 0.2mm hydrophone (transducer excited with 50 cycles, low drive levels to avoid hydrophone damage)



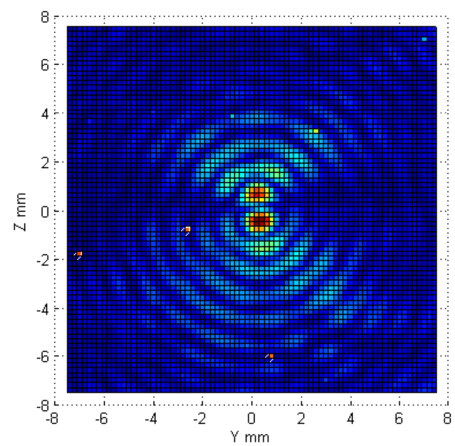
The HIFU field – in water



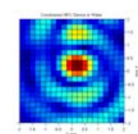


HIFU beam scanned across central plane and sensor response recorded

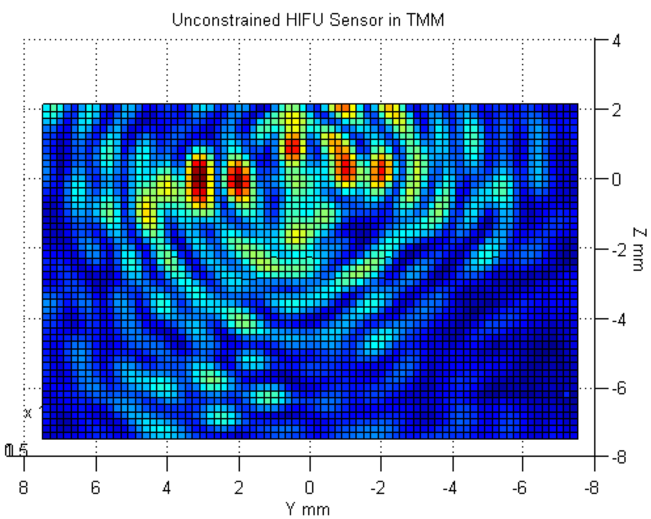
Unconstrained sensor



Constrained sensor



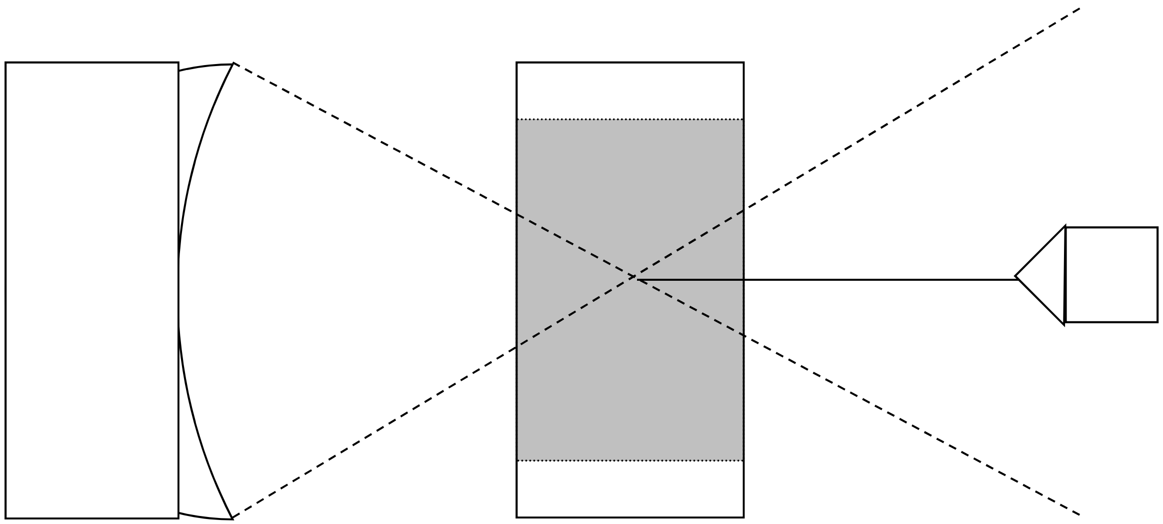
The HIFU field – in TMM

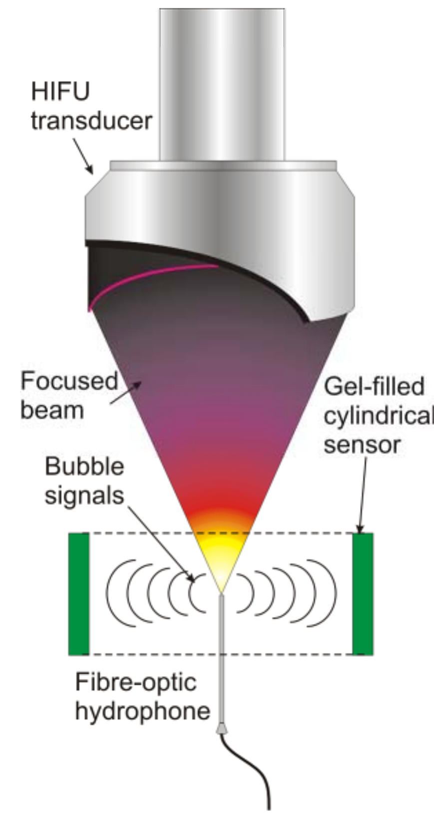


- De-ionised water with 3%wt agar
- No additives for scattering or absorption
- Attenuation measured using broadband technique

➢ 0.25 dB/cm/MHz

Co-location of sensors





1- Transducer vs. Empty HIFU cav sensor

2- Transducer vs. Capillary tube

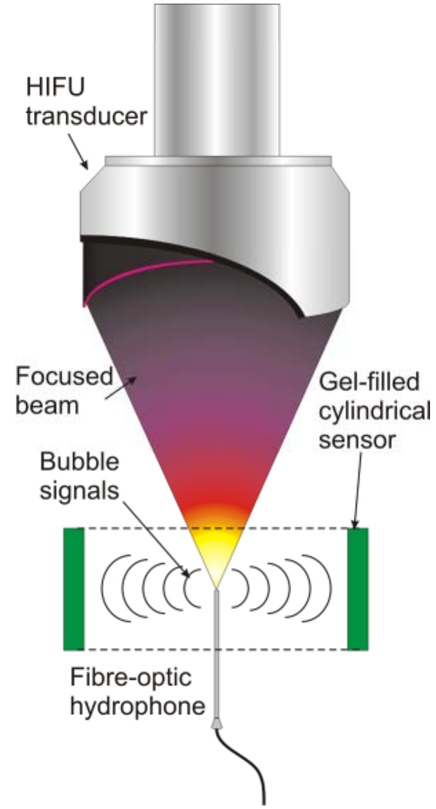
3- Transducer vs. TMM-filled HIFU cav sensor

4- Inserting capillary tube

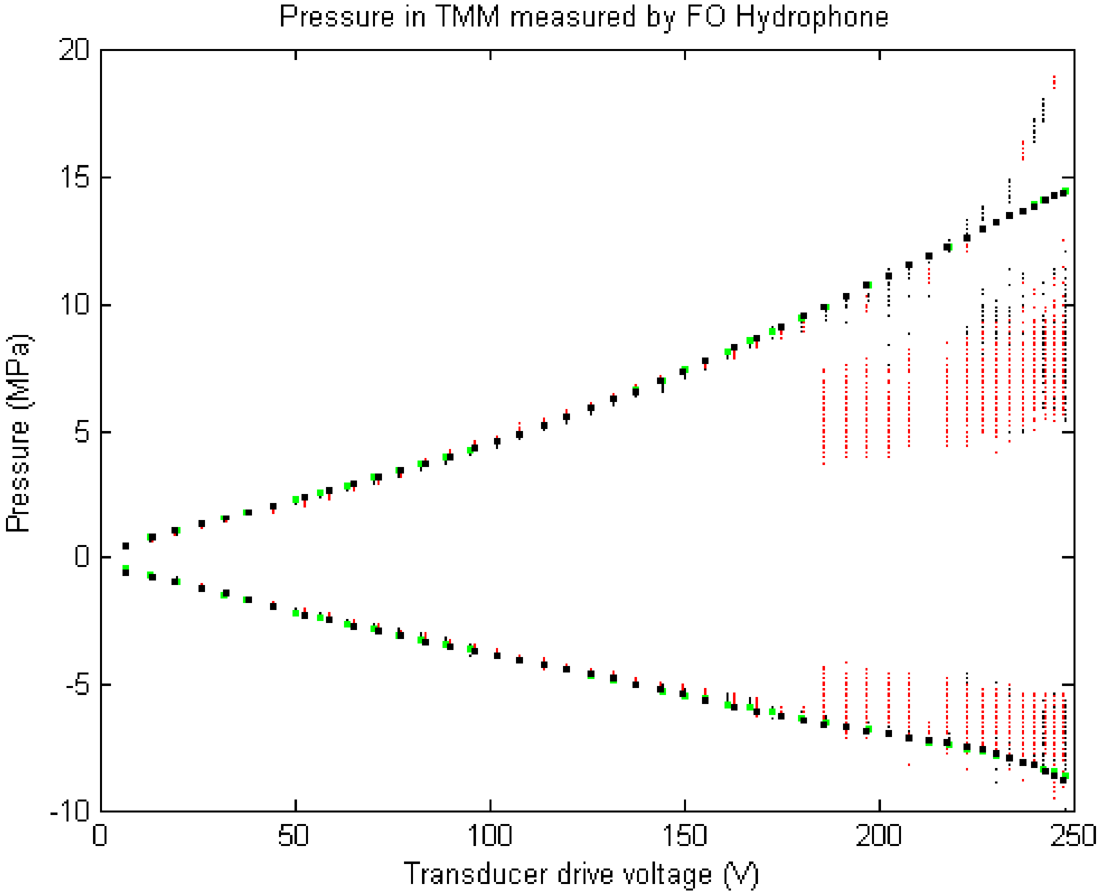
5- Fibre-optic hydrophone inserted into TMM

Dual-sensor measurements

- Measurements made as a function of drive level on Agilent 33250A Signal Generator, driving Sonic Concepts 1.1MHz transducer through AR 150A100B RF power amplifier
- 100 single-shot waveforms, recorded at 45 excitation voltage settings, each of transducer drive, fibre-optic hydrophone and cavitation sensor outputs
- Carried out with water and with TMM as the experimental medium



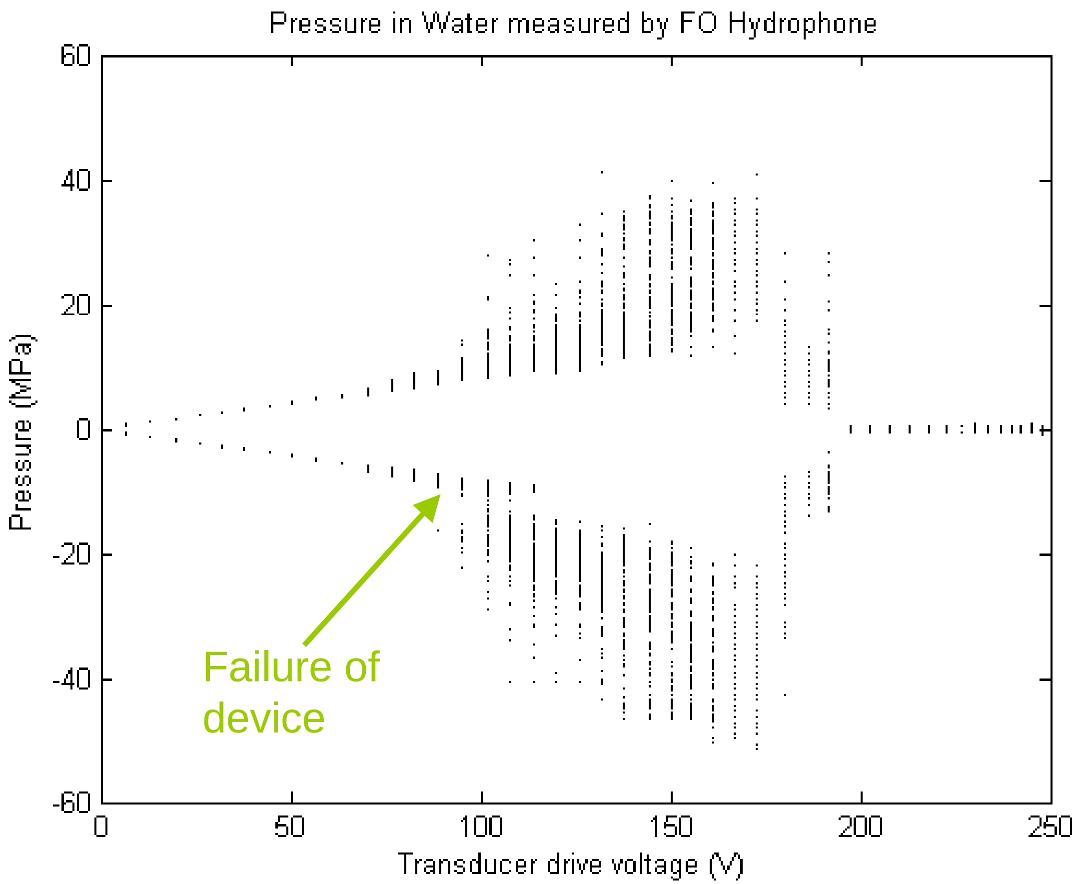
Pressure at the HIFU focus



Black = ascending drive; red = descending

- F/O hydrophone located off-axis to minimise damage
- Measured pressures corrected to provide effective focal values, using cross-axial data from initial low-drive measurements in water

Pressure at the HIFU focus



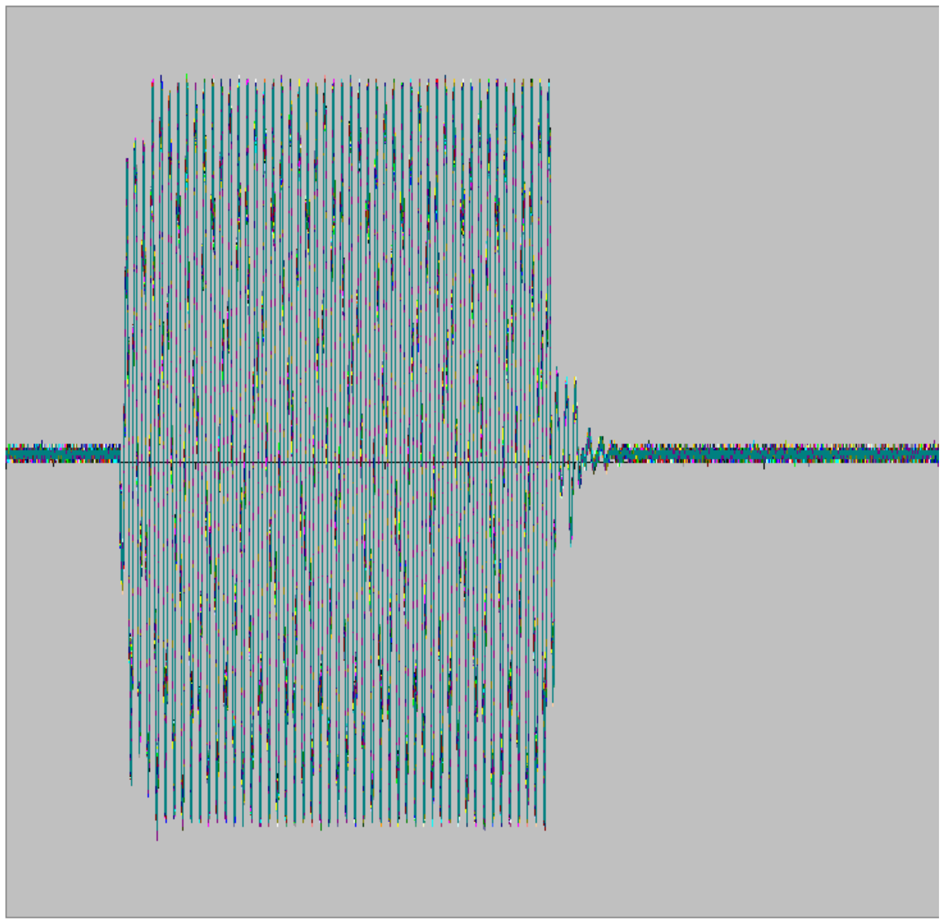
Black = ascending drive

- F/O hydrophone located off-axis to minimise damage – yet hydrophone still unable to withstand high drive levels
- Measured pressures corrected to provide effective focal values, using cross-axial data from initial low-drive measurements in water

Results

In TMM

Transducer drive signal (probed)



Results

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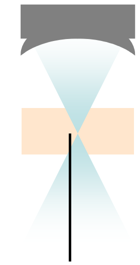
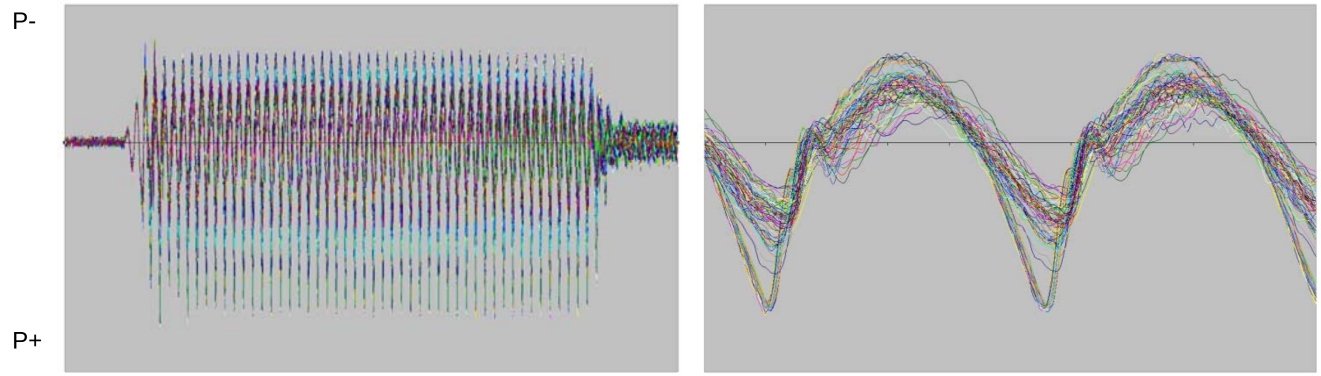
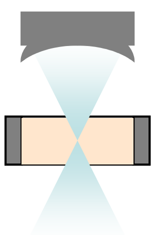
In TMM



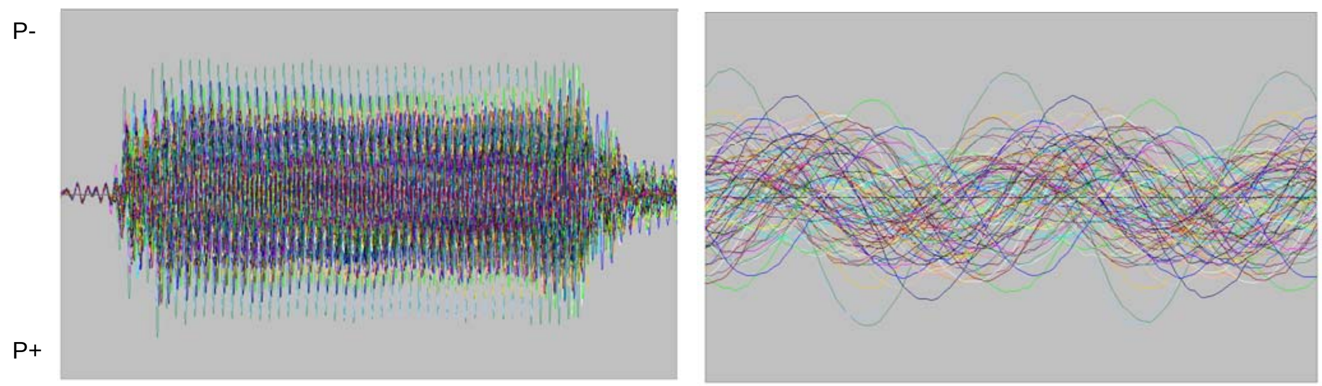
Fibre optic hydrophone



Dominated by driving field



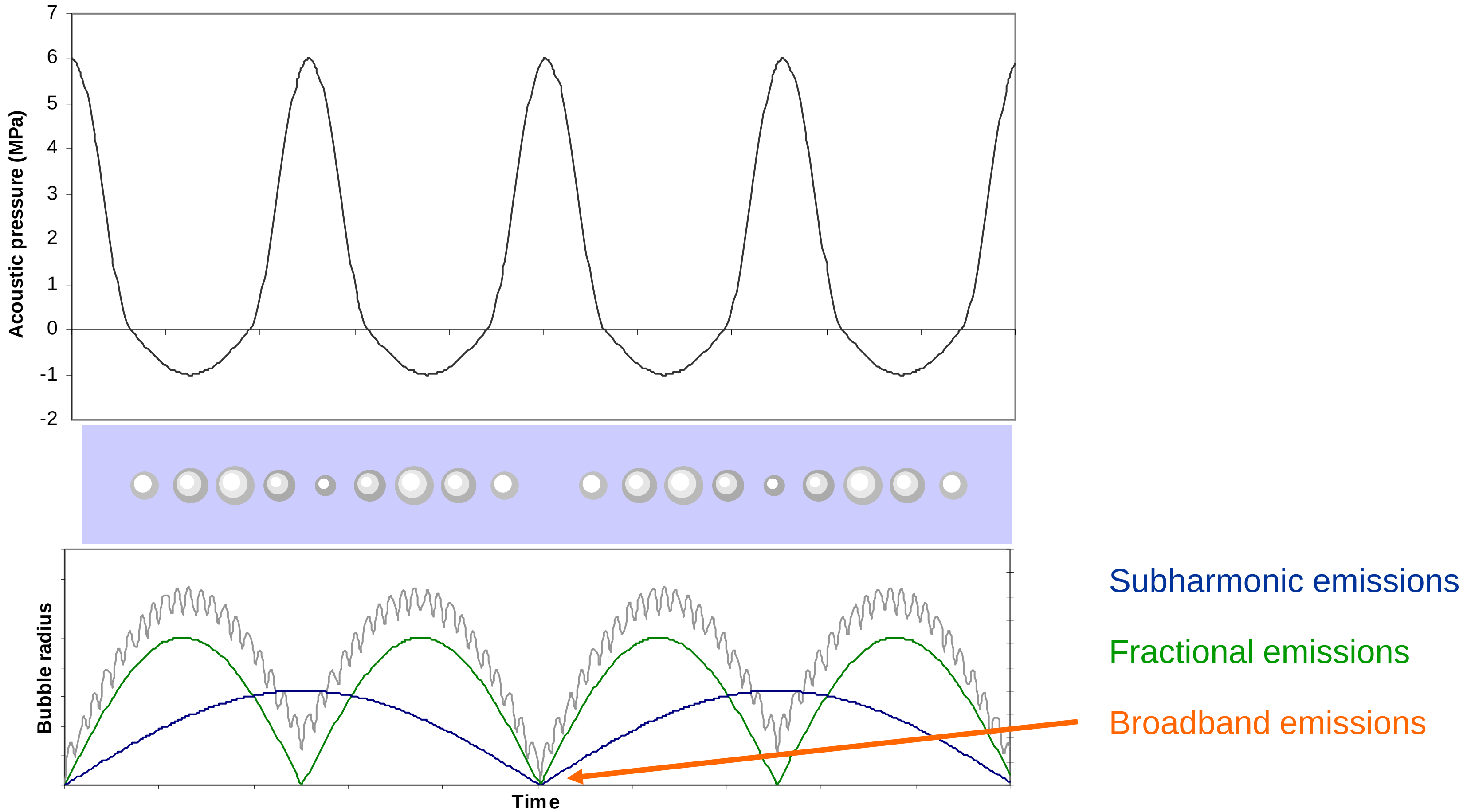
HIFU cav sensor



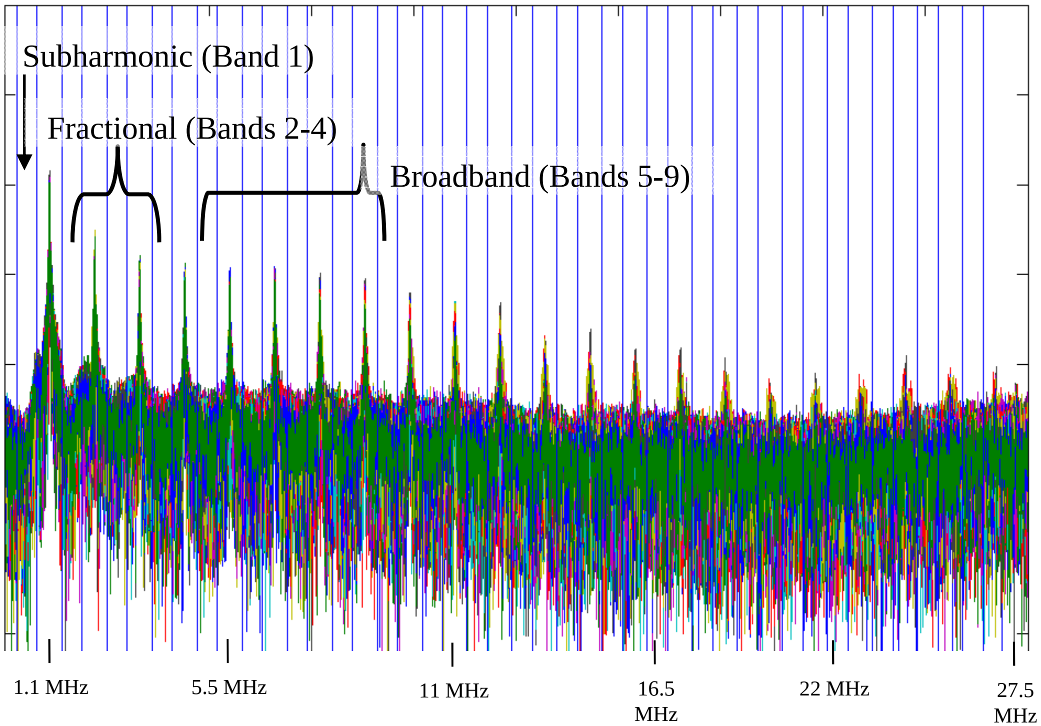
Cavitation emissions much more dominant

(plus driving field reflected off bubbles..)

The characteristics of cavitation



Cavitation indicators

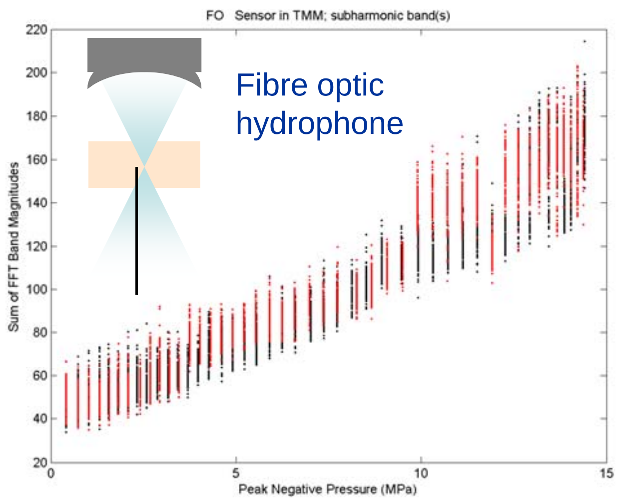


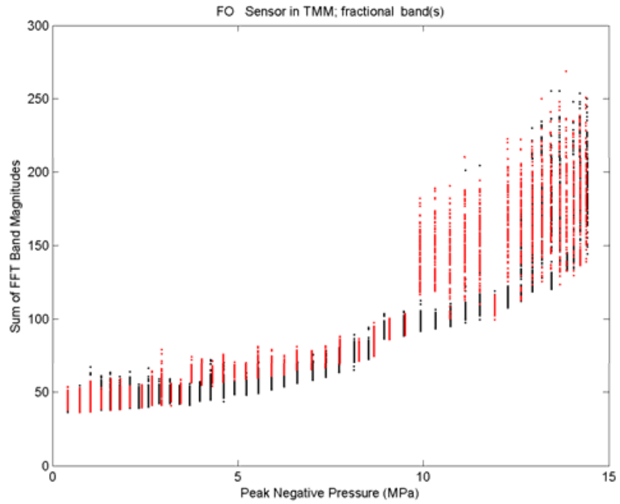
Band No.	Lower (MHz)	Upper (MHz)	
1	0.3	0.8	Subharmonic
2	1.4	1.9	
3	2.5	3	Fractional
4	3.6	4.1	
5	4.7	5.2	
6	5.8	6.3	
7	6.9	7.4	Broadband
8	8	8.5	
9	9.1	9.6	

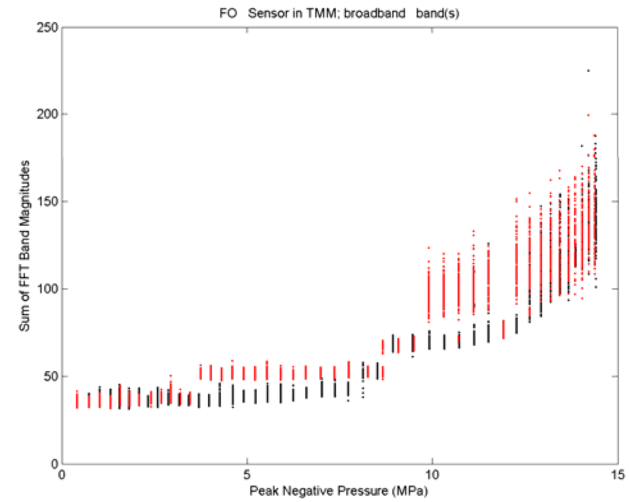
Results

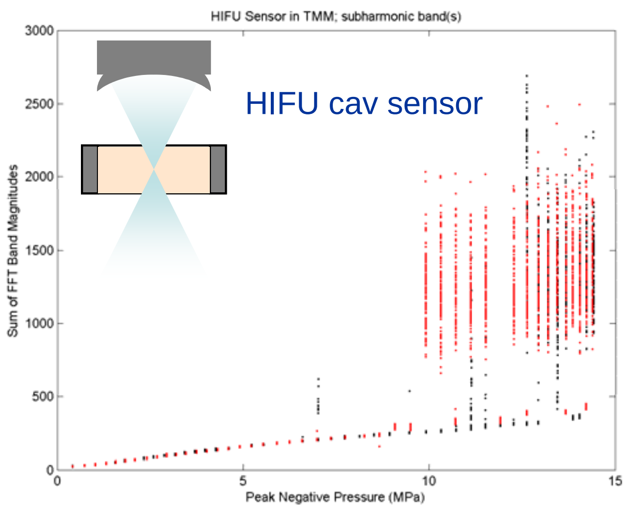
In TMM

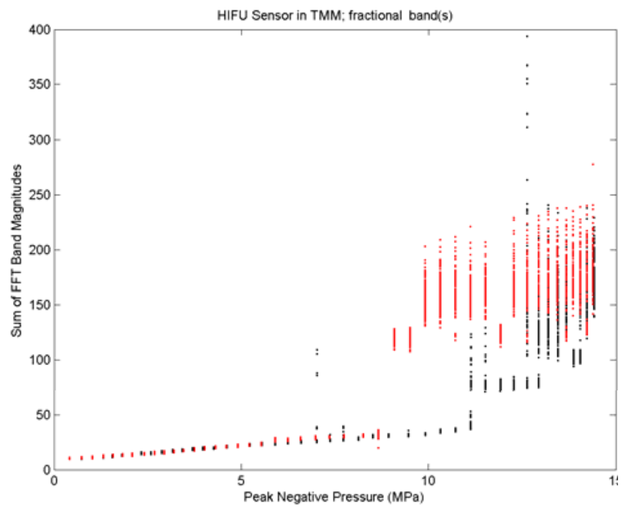
Black = ascending drive; red = descending

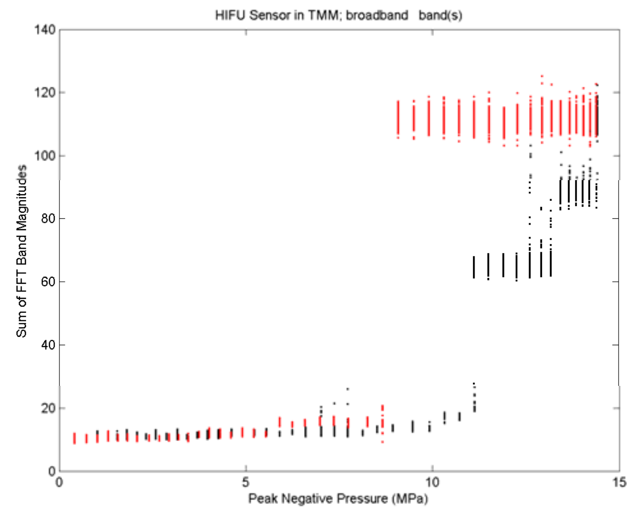




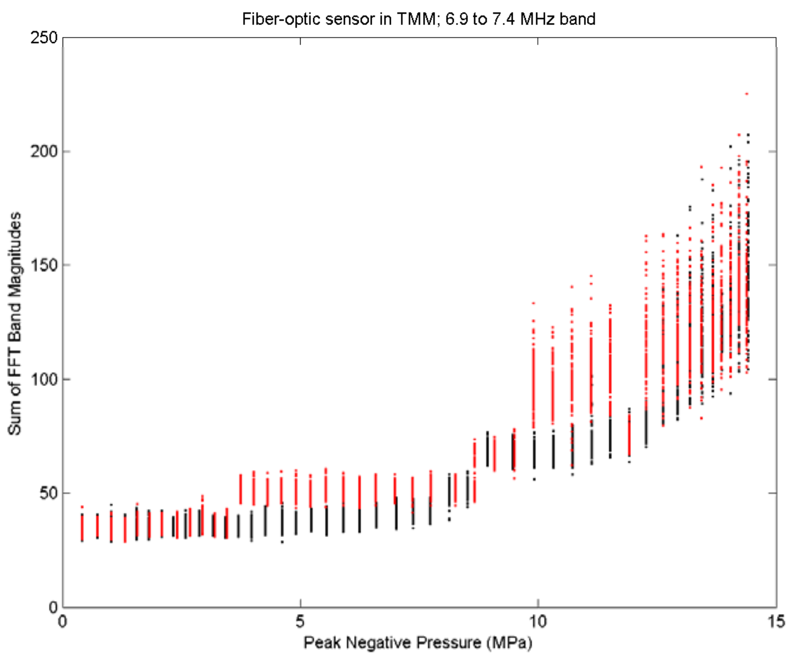


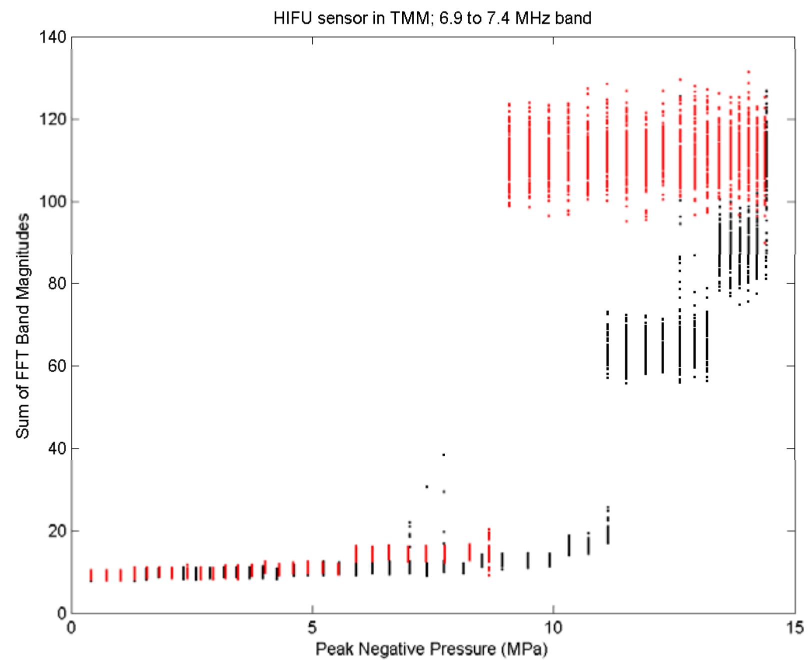






Results – broadband detail

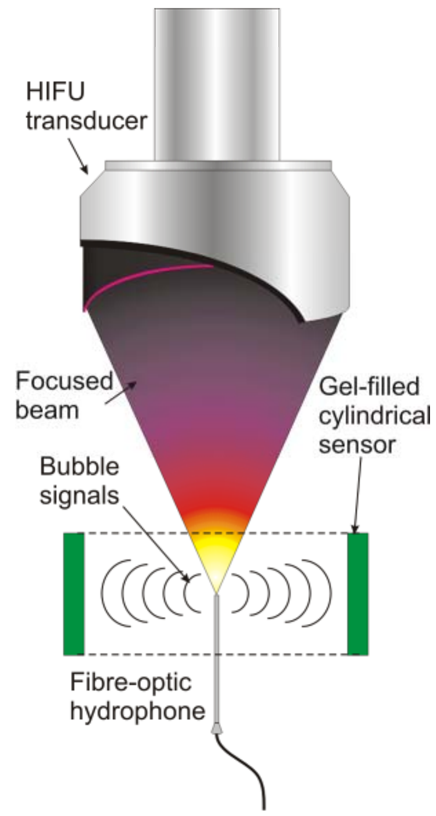




- Suggests narrower on-axis spatial response for HIFU sensor

Conclusions

- Simultaneous deployment of a fibre-optic hydrophone and a novel cylindrically-focused sensor has demonstrated, through three indicators, the onset and activity level of cavitation
- Clearer ‘step’ thresholds are seen with the cavitation sensor (~6 MPa in TMM), probably due to its focused characteristic
- Clear hysteresis is seen when comparing ascending and descending drive level results



Further work

- Trial the sensors with:
  - A range of clinical transducers and exposure conditions (frequency, pulse characteristics)
  - Other TMMs and real tissues
- Investigate hysteresis in more detail – how does the TMM change with cumulative exposure?
- Cast F/O hydrophone into TMM directly

Acknowledgements: NPL Strategic Research Programme; Victoria Bull (Institute of Cancer Research) and Neelaksh Sadhoo