Comparison of Viscoelastic Properties of CIRS Phantoms and Human Liver

Ned Rouze

March 21, 2014

DUKE BIOMEDICAL ENGINEERING

Overview

One goal of QIBA phase II is to construct phantoms with viscoelastic properties similar to human liver

Our group has agreed to perform an initial evaluation of these phantoms by comparing results with similar measurements in our population of 135 NAFLD patients

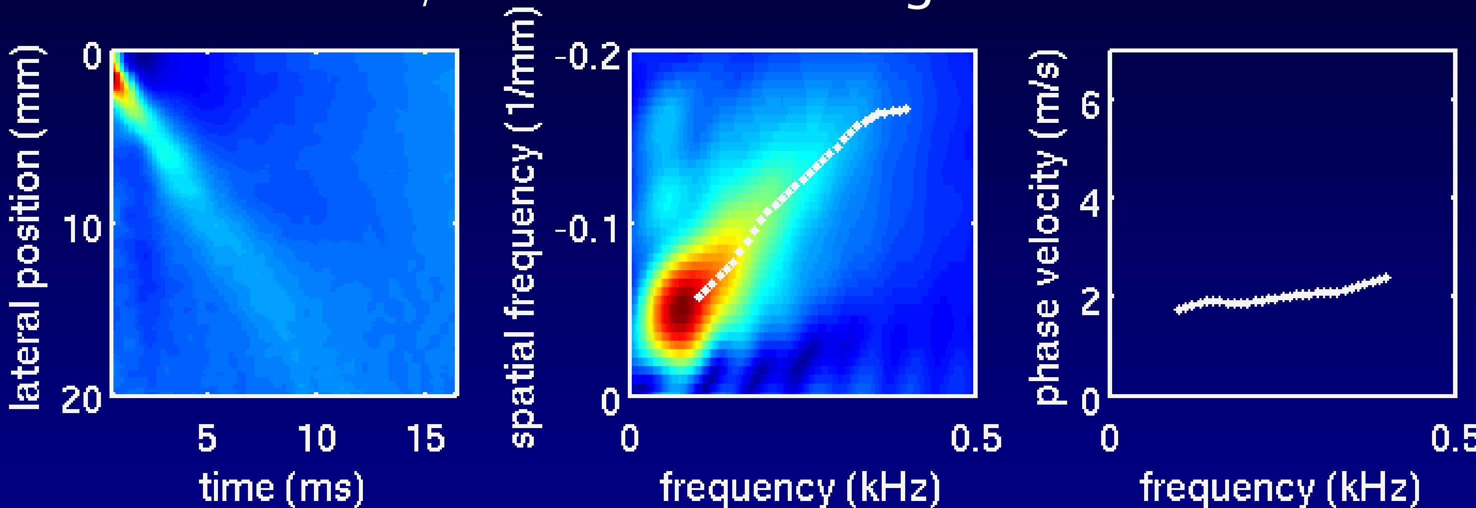
These patients are “difficult to image”
our human liver data are noisy

Primarily, our efforts have been focused on developing methods that work in our patient data

Then, use this procedure for characterization of the phantoms and compare with similar measurements in liver

Sample Data in F1 Liver

particle velocity SWS = 2.01 m/s | 2D–FT no windowing no filtering | phase velocity



phase velocity $c(\omega) = \omega/k$

k from maximum 2D-FT signal at each temporal frequency

frequency range: 100 – 400 Hz

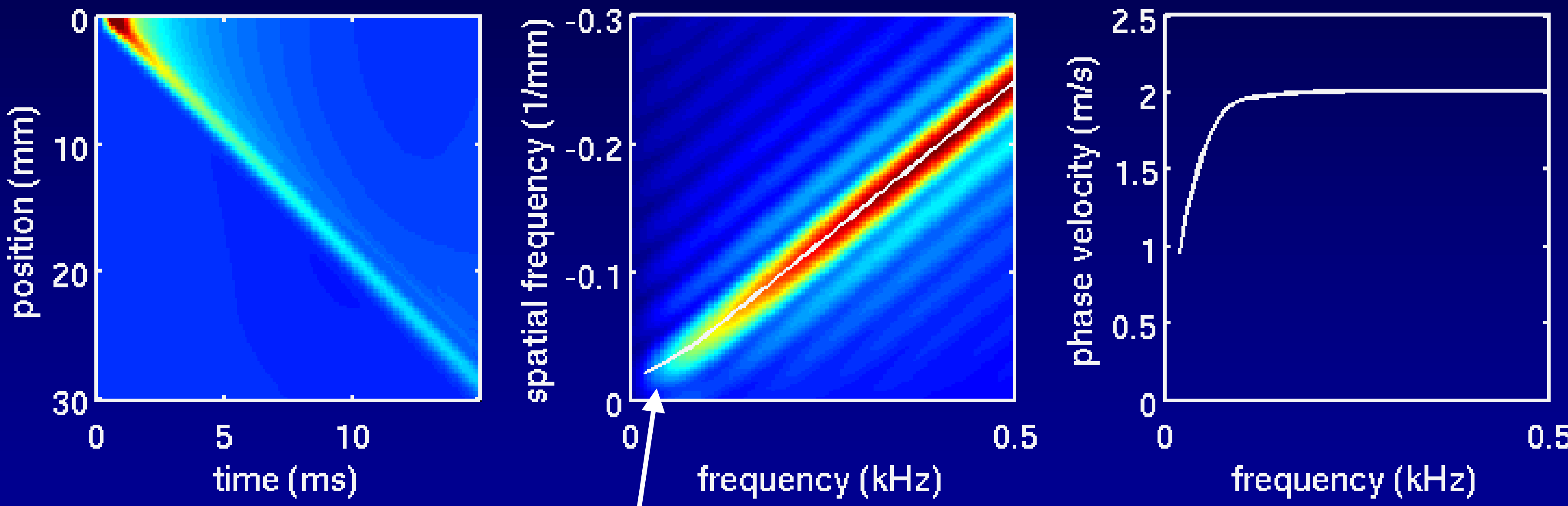
- determined empirically from liver data
- consistent with frequencies used in commercial scanners
- avoids bias at low frequency

Bias in Phase Velocity at Low Frequency

FE simulation using elastic material with E = 12 kPa

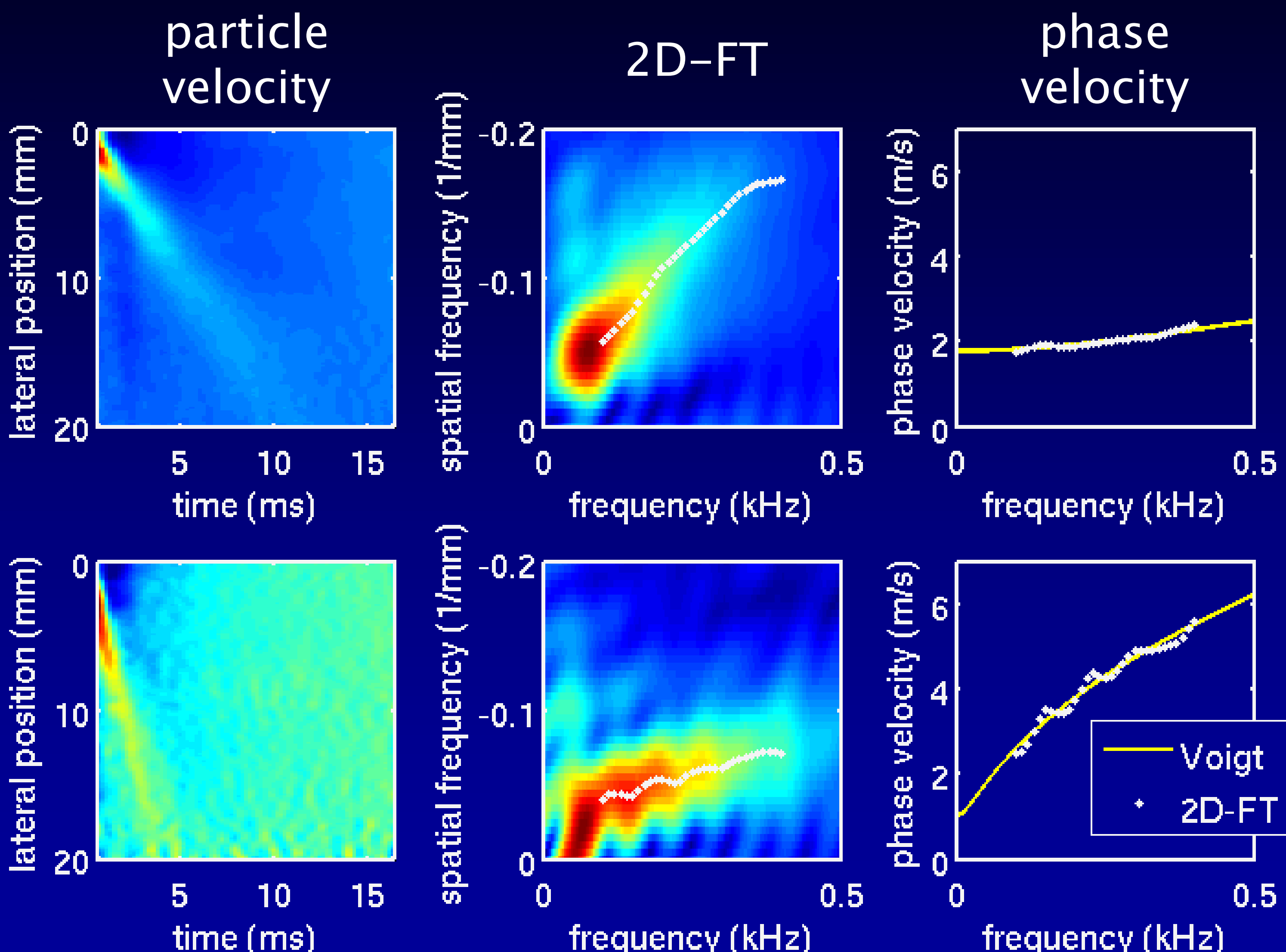
Expect $c(f) = 2\ \mathrm{m/s}$ (constant)

particle velocity | 2D–FT | phase velocity



Maximum in 2D–FT along temporal frequency deviates from constant velocity at low frequencies

F1, F3 Liver Cases, Voigt model Analysis



F1
SWS = 2.01 m/s
μ = 3.17 kPa
η = 1.25 Pa s

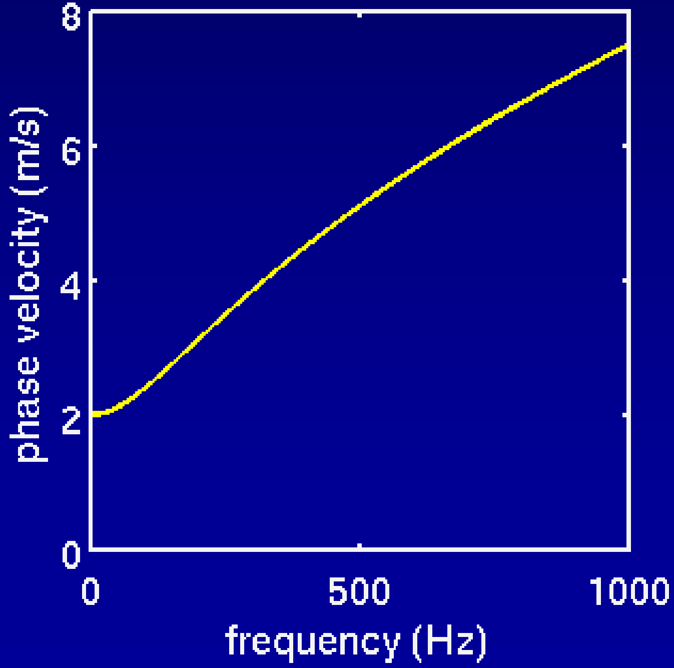
F3
SWS = 4.88 m/s
μ = 1.07 kPa
η = 6.48 Pa s

Issues with Voigt model

$$c(\omega) = \sqrt{\frac{2(\mu^2 + \omega^2\eta^2)}{\rho\left(\mu + \sqrt{\mu^2 + \omega^2\eta^2}\right)}}$$

$\mu = 4$ kPa, $\eta = 5$ Pa-s

Inflection point at $\sim$180 Hz



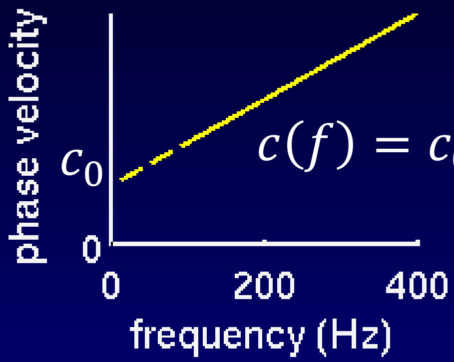
- Both positive and negative curvature

- μ may not characterize phase velocity if there is significant dispersion

$$c(0\text{ Hz}) = \sqrt{\mu/\rho}$$

Current Analysis Method

Linear dispersion model



Estimate c_0 and $\frac{dc}{df}$ using Radon-like sums along curved paths in 2D-FT

$$S\left(c_0, \frac{dc}{df}\right) = \sum_i \left| U\left(k\left(c_0, \frac{dc}{df}, \omega_i\right), \omega_i\right) \right|^2$$

Frequency range: 100 – 400 Hz

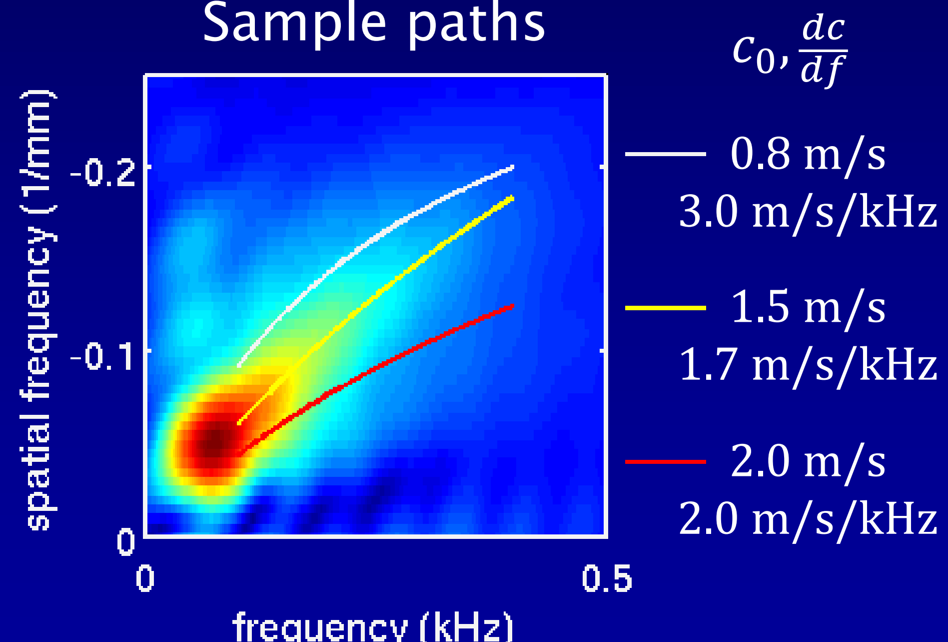
Determine $c_0, \frac{dc}{df}$ from max sum

Sums weighted by 2D-FT energy

Sum is robust to outlier data

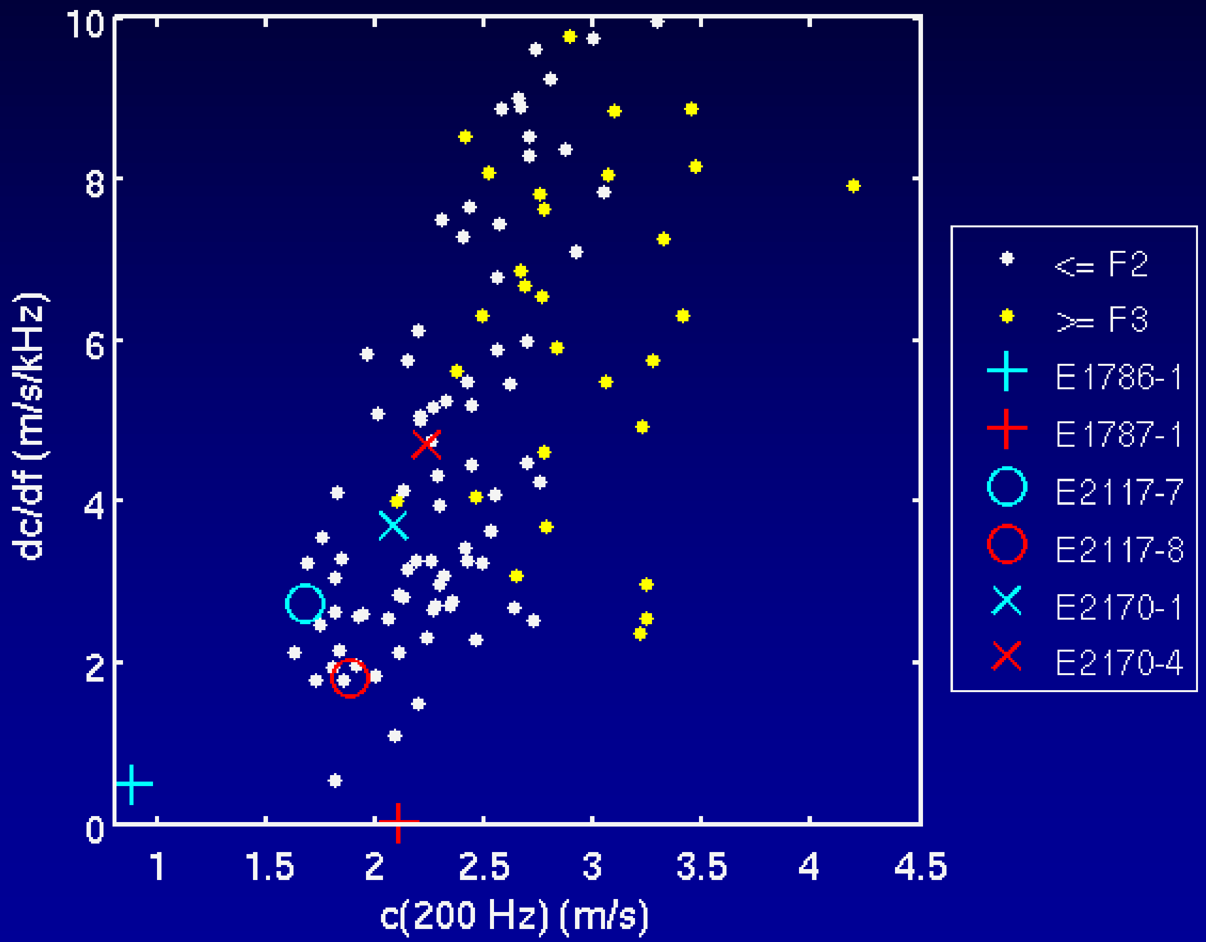
Report c(200 Hz), $\frac{dc}{df}$

Sample paths



Comparison of phantom and liver data

Successful fits in 107 patients



Phase 1 QIBA

CIRS January

CIRS March

Conclusion

Comparison of CIRS phantoms with human liver data is improving

$$\text{Human Liver Data over } f = 100 - 400 \text{ Hz}$$

$$c(200 \text{ Hz}) \sim 1.5 - 4 \text{ m/s}$$

$$\frac{dc}{df} \sim 1 - 10 \text{ m/s/kHz}$$

Ted Lynch is preparing one more set of phantoms