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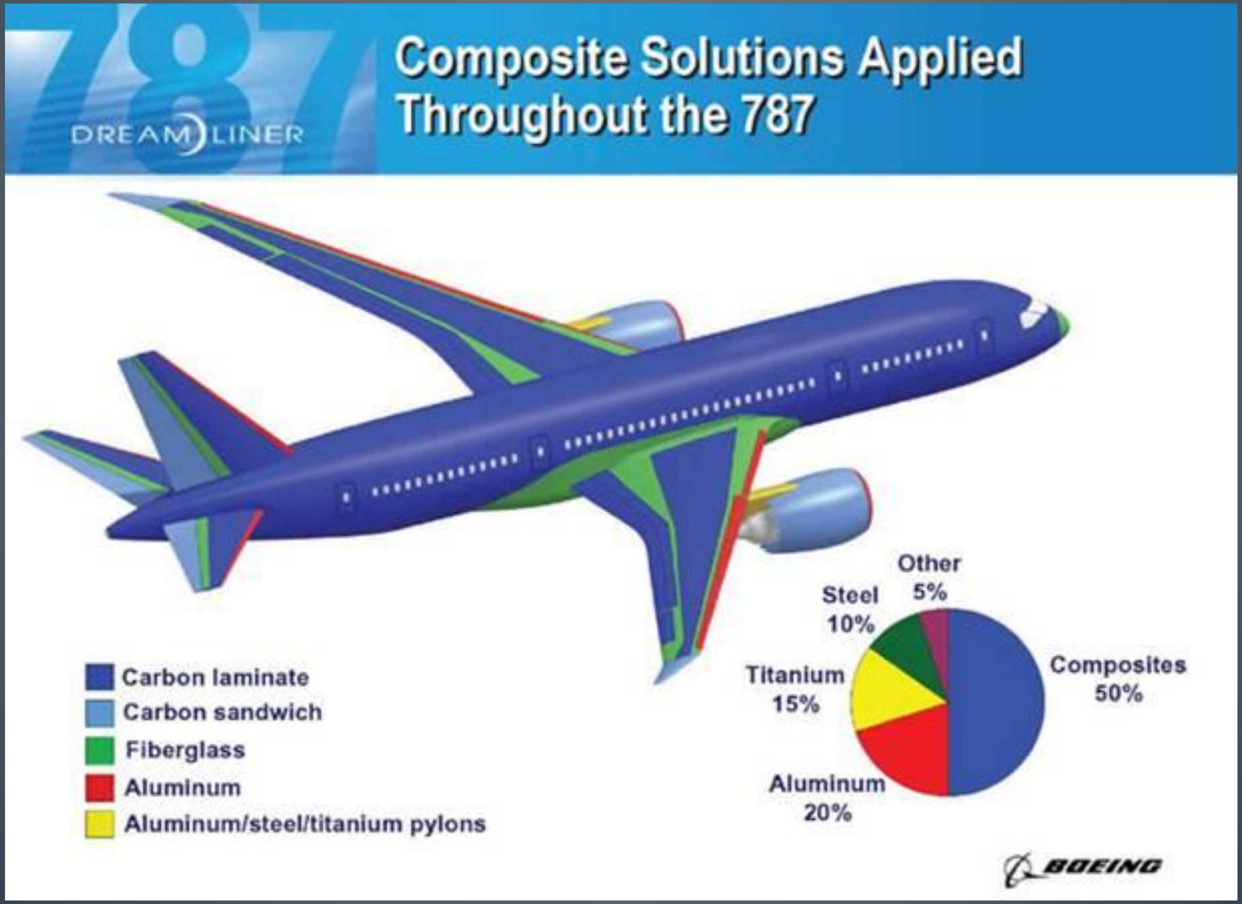
June 22 – 26, 2015

Composite characterization using laser Doppler vibrometry and multi-frequency wavenumber analysis

By Peter Juarez and Dr. Cara Leckey

NASA Langley Research Center
Nondestructive Evaluation Sciences Branch

Motivation


DREAMLINER
Composite Solutions Applied
Throughout the 787
Carbon laminate
Carbon sandwich
Fiberglass
Aluminum
Aluminum/steel/titanium pylons
Other
5%
Steel
10%
Titanium
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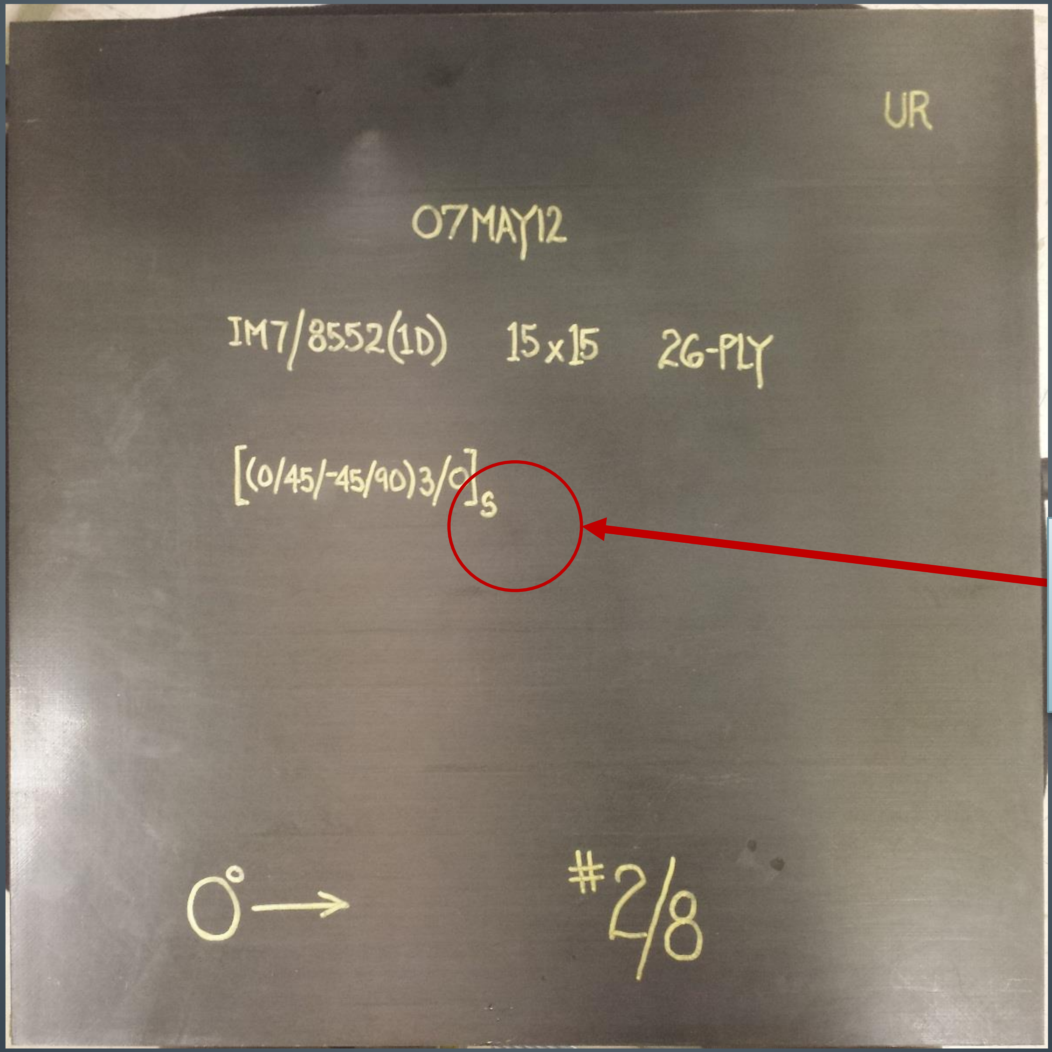
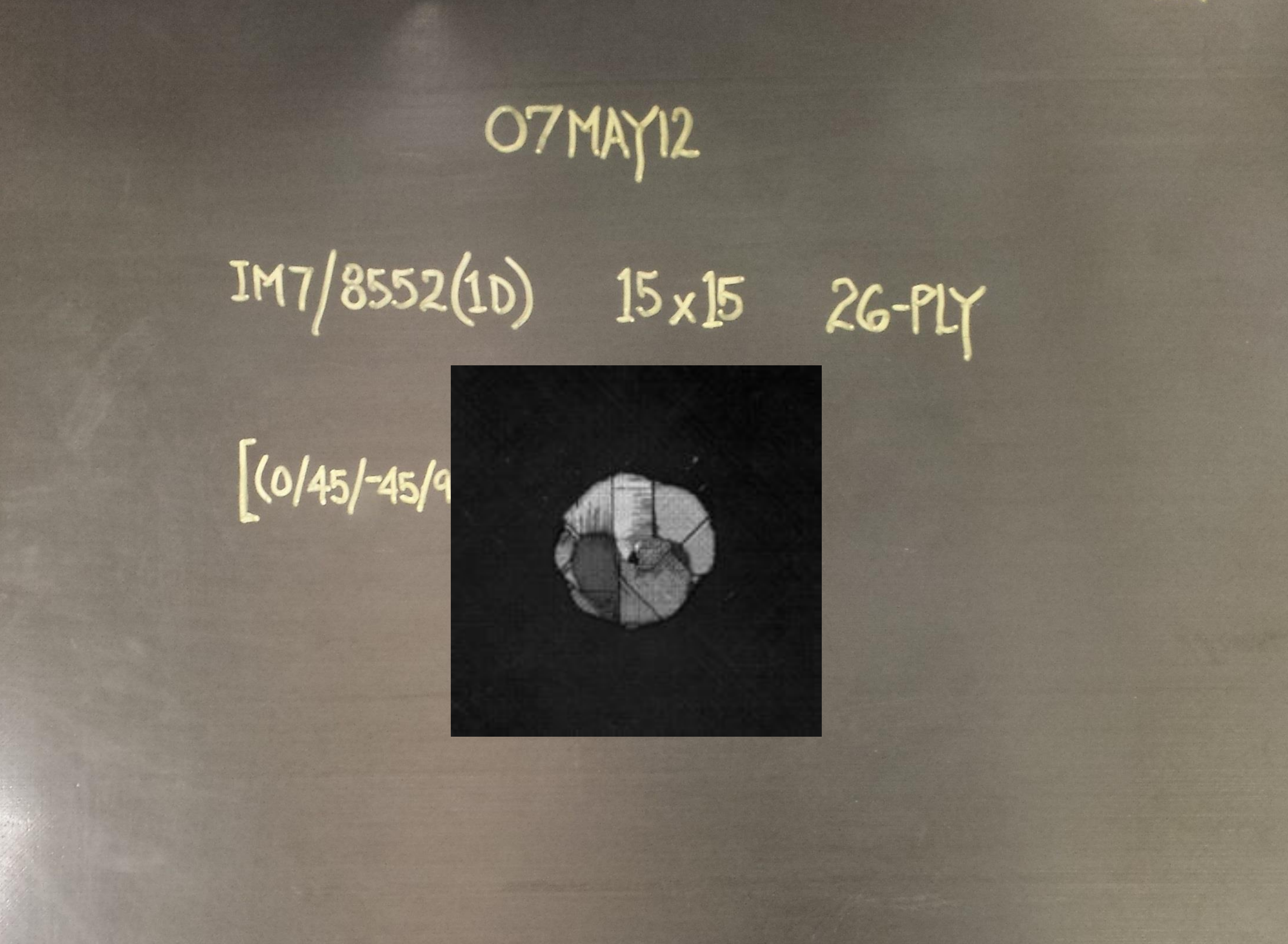
Aluminum
20%
Composites
50%
BOEING

Motivation

Nondestructive
Evaluation
Sciences Branch



Barely Visible
Damage
(BVD)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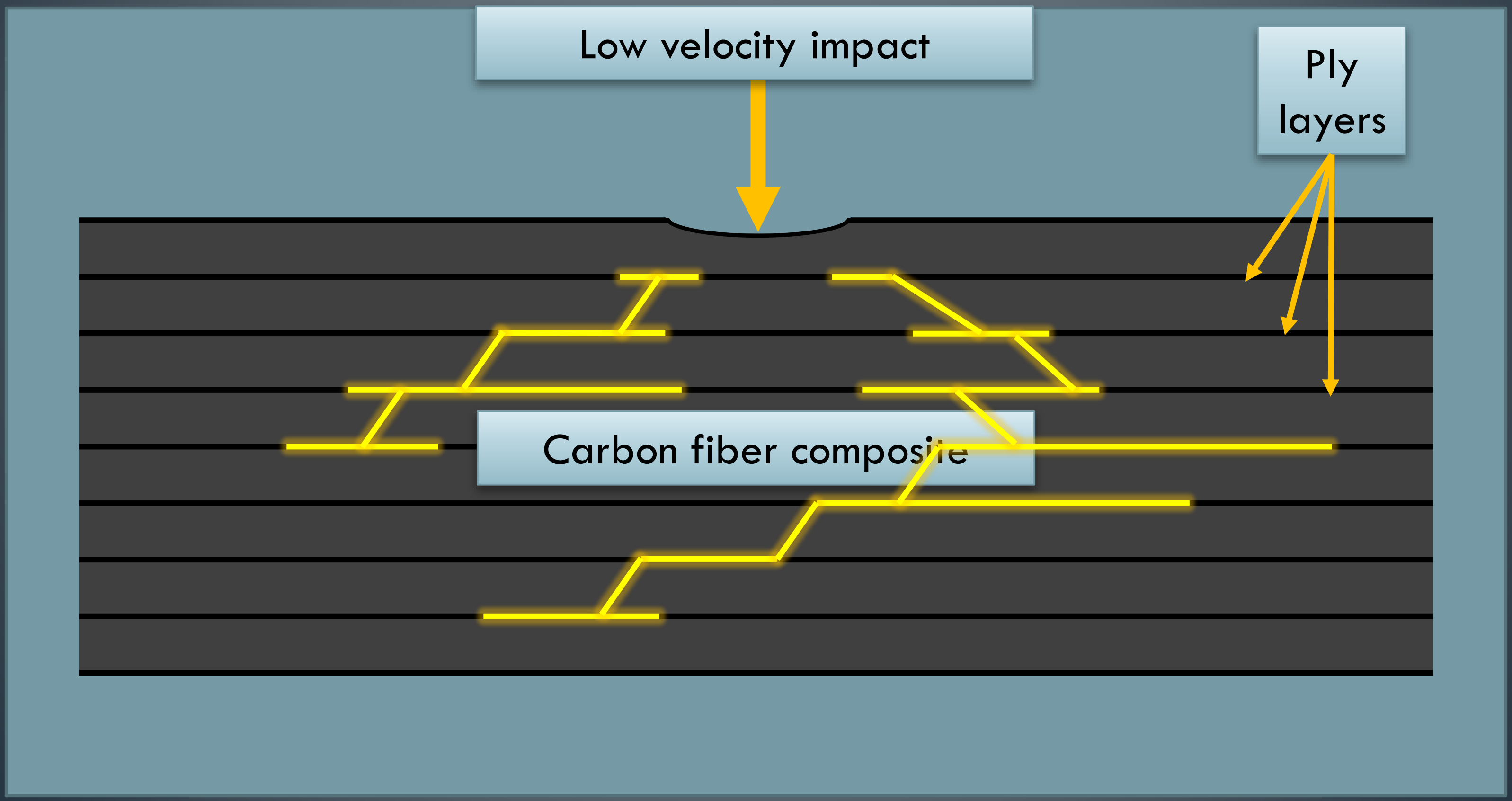
[(0/45/-45/9

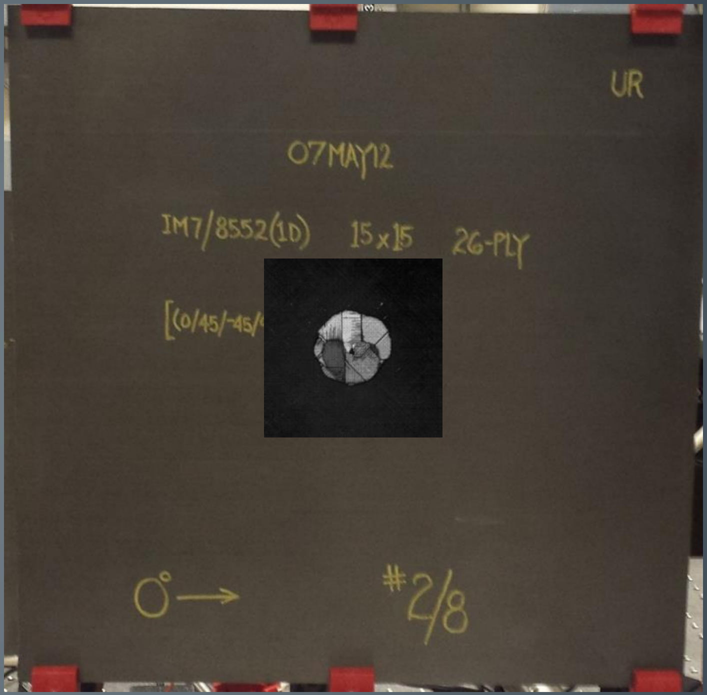
Motivation

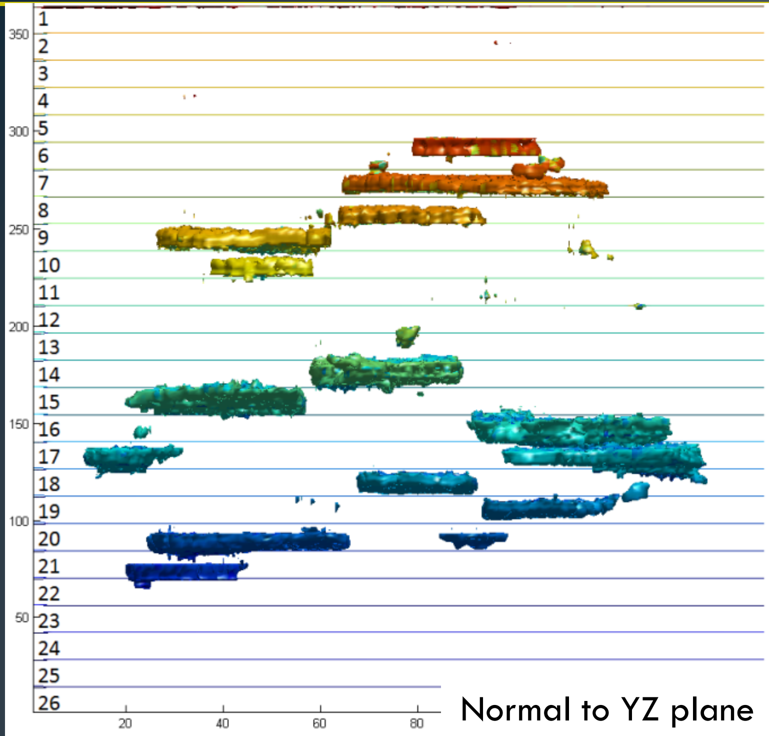
Nondestructive
Evaluation
Sciences Branch



Goal of research

- 26 ply carbon fiber panel 15”x15”, quasi-isotropic layup ($[0/45/-45/90]_3/0)_s$
- Damaged using a static point load of 1511 lbf until failure, then scanned using a traditional nondestructive evaluation technique (ultrasonic immersion tank scanning)

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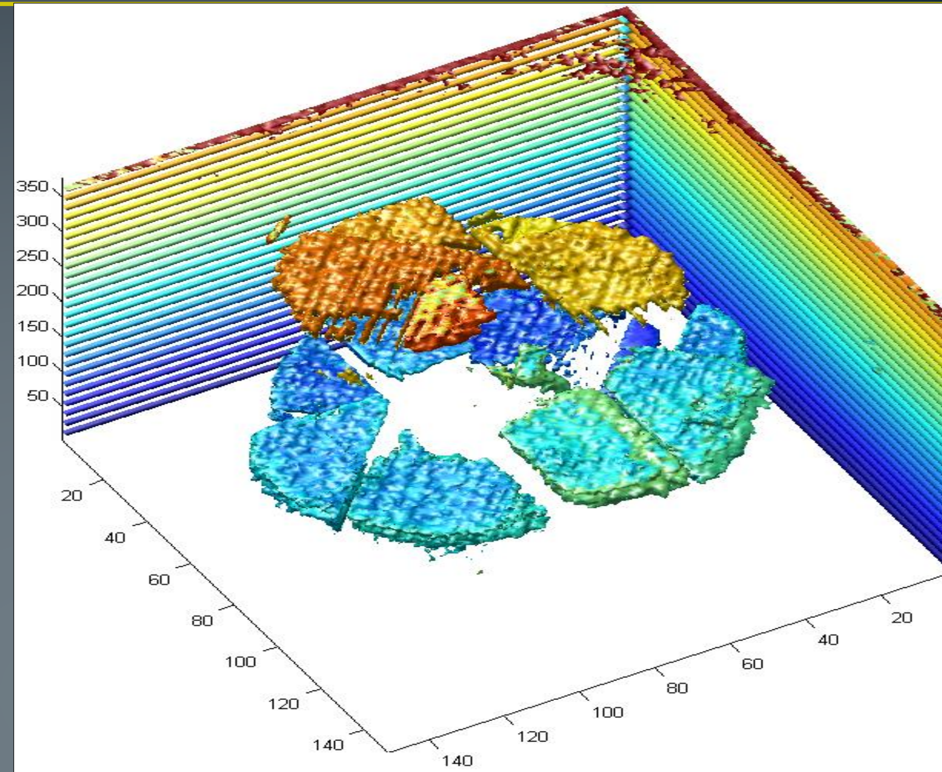
80
Normal to YZ plane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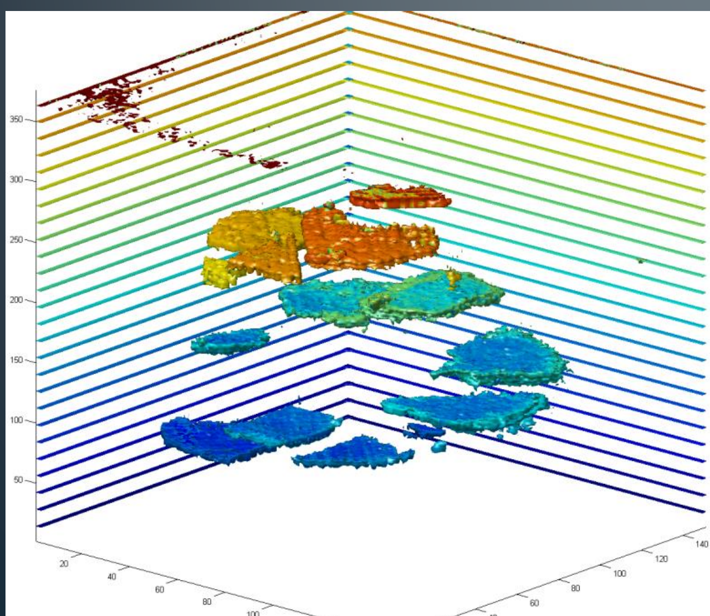

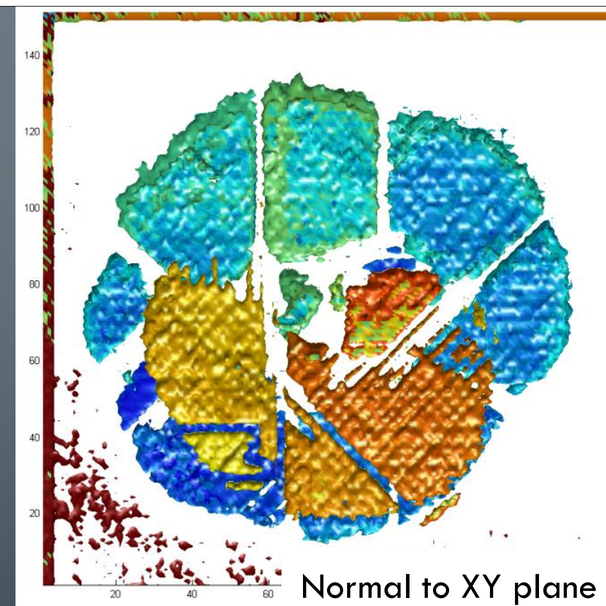
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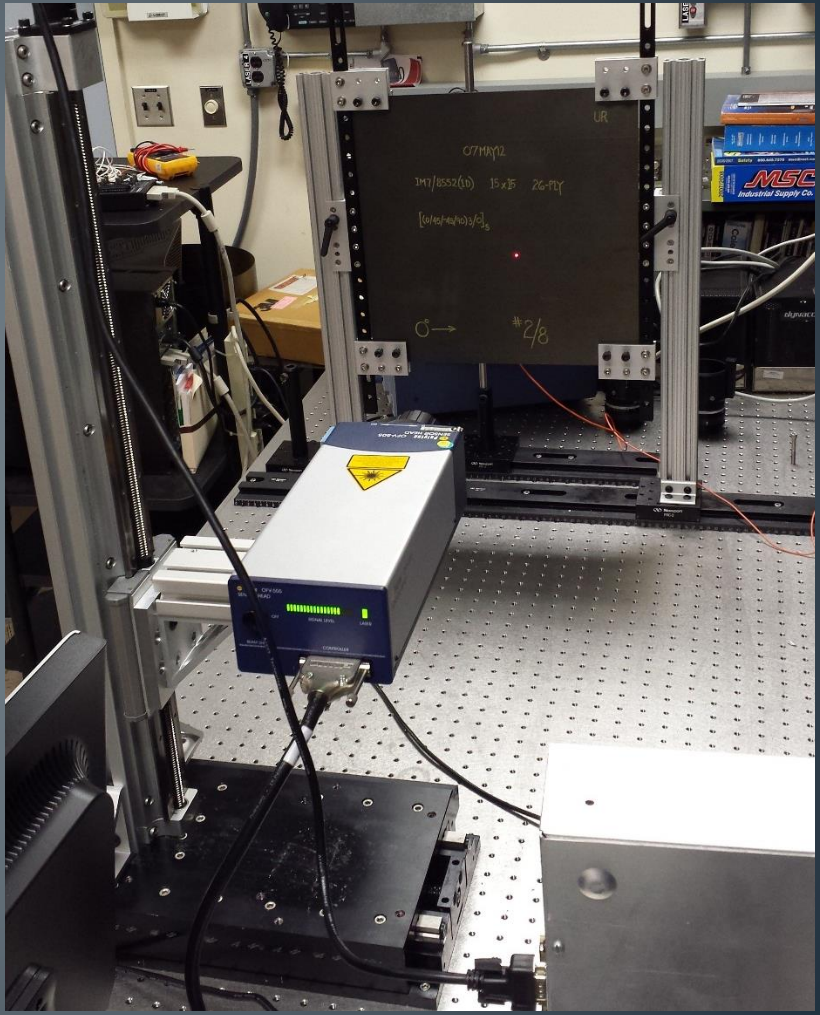
Normal to XY plane

Goal of research

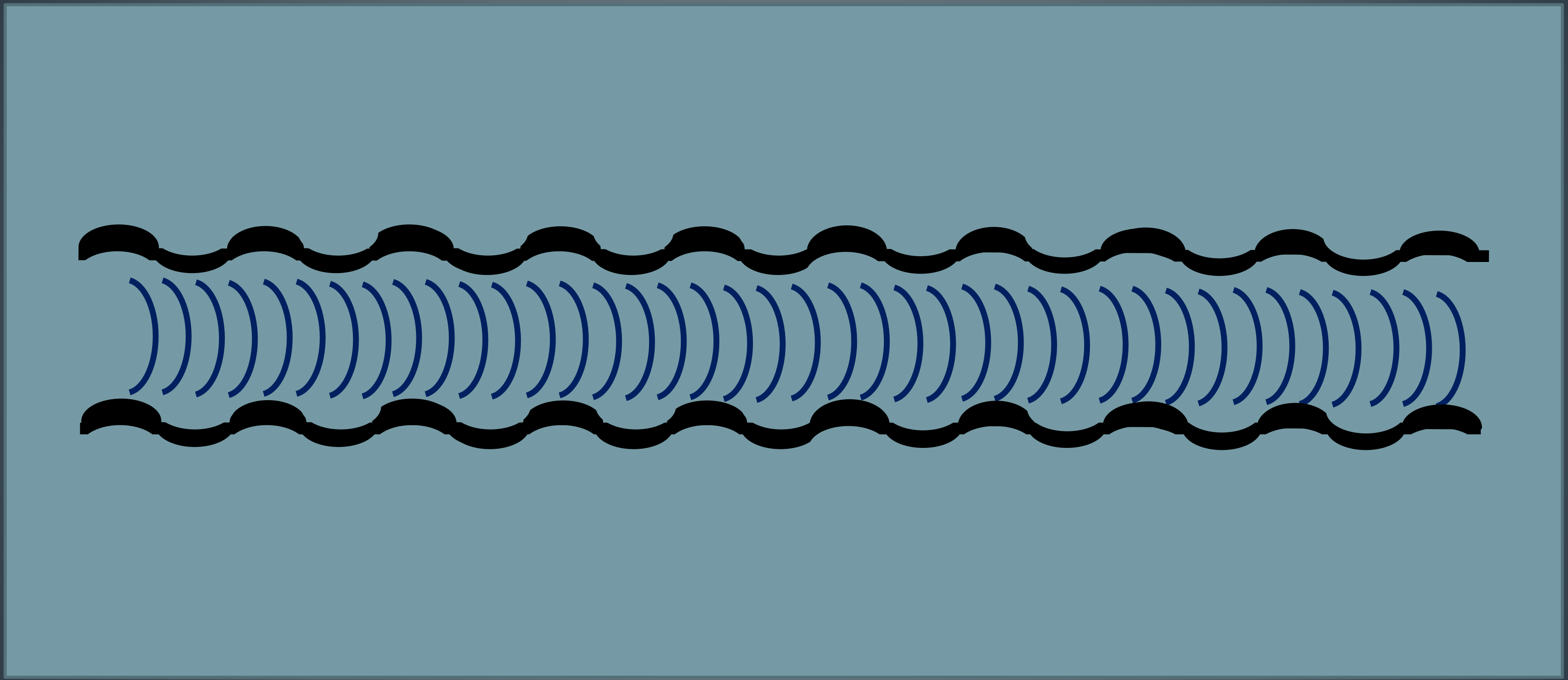
Nondestructive
Evaluation
Sciences Branch

- Data was collected from a Scanning Laser Doppler Vibrometer (SLDV) while acoustic waves were excited in the panel with a contact transducer

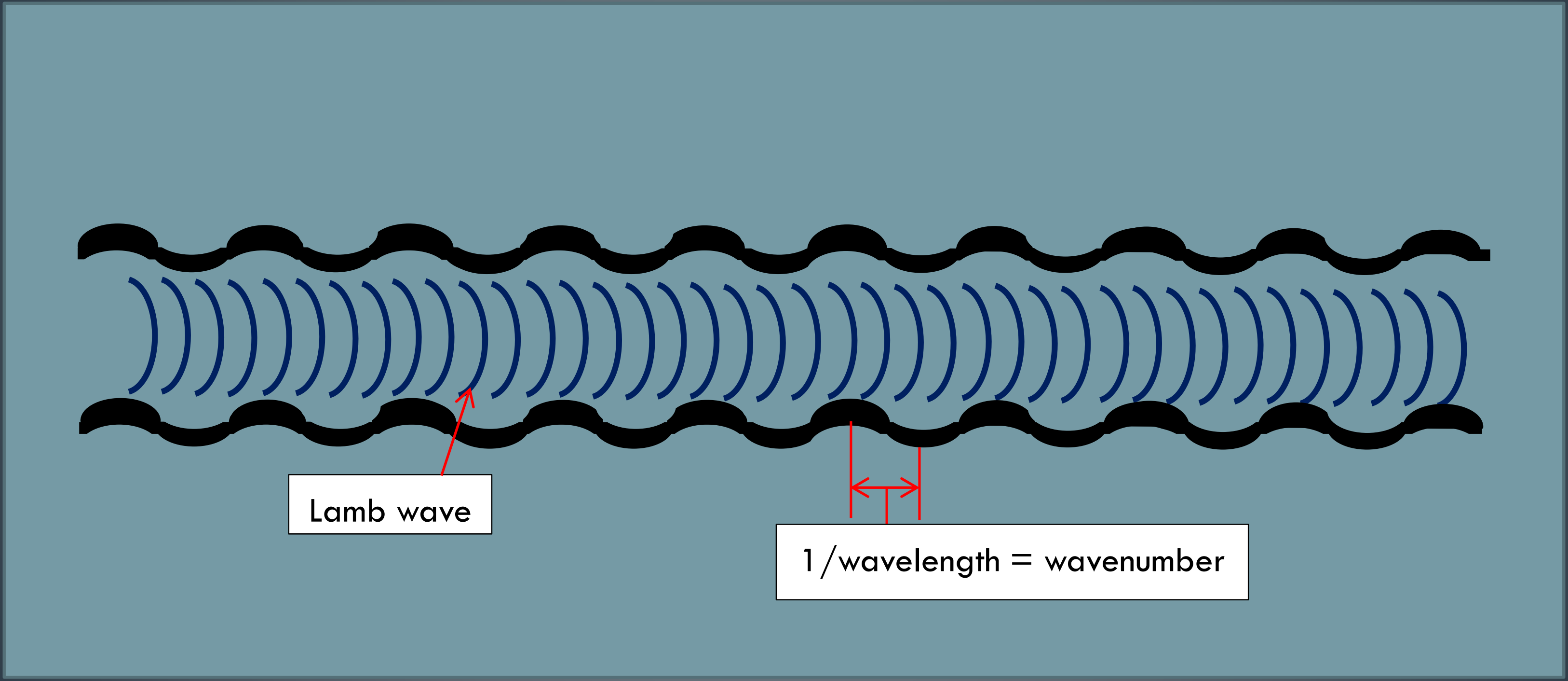
- Goal: to correlate the SLDV data to the size and depth of the delaminations in the composite



What are we detecting?

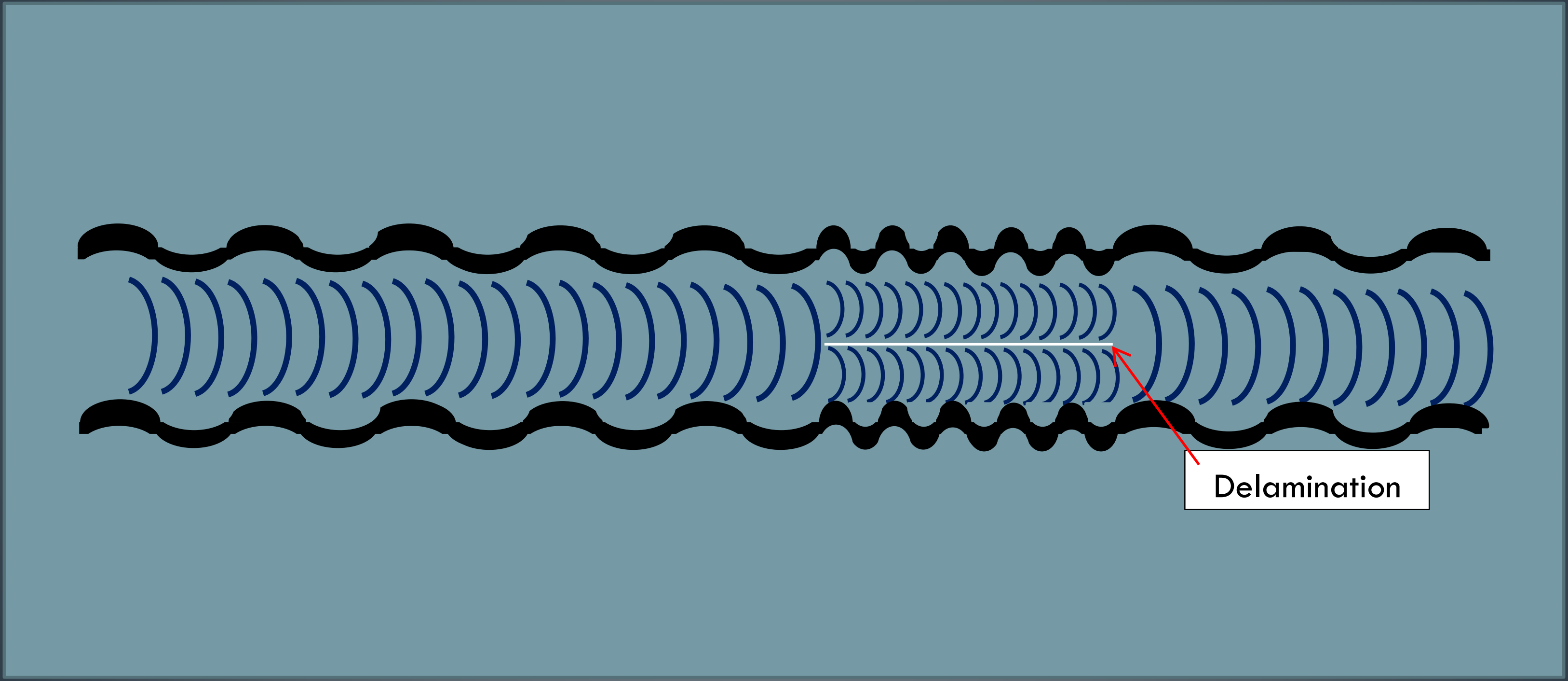


What are we detecting?



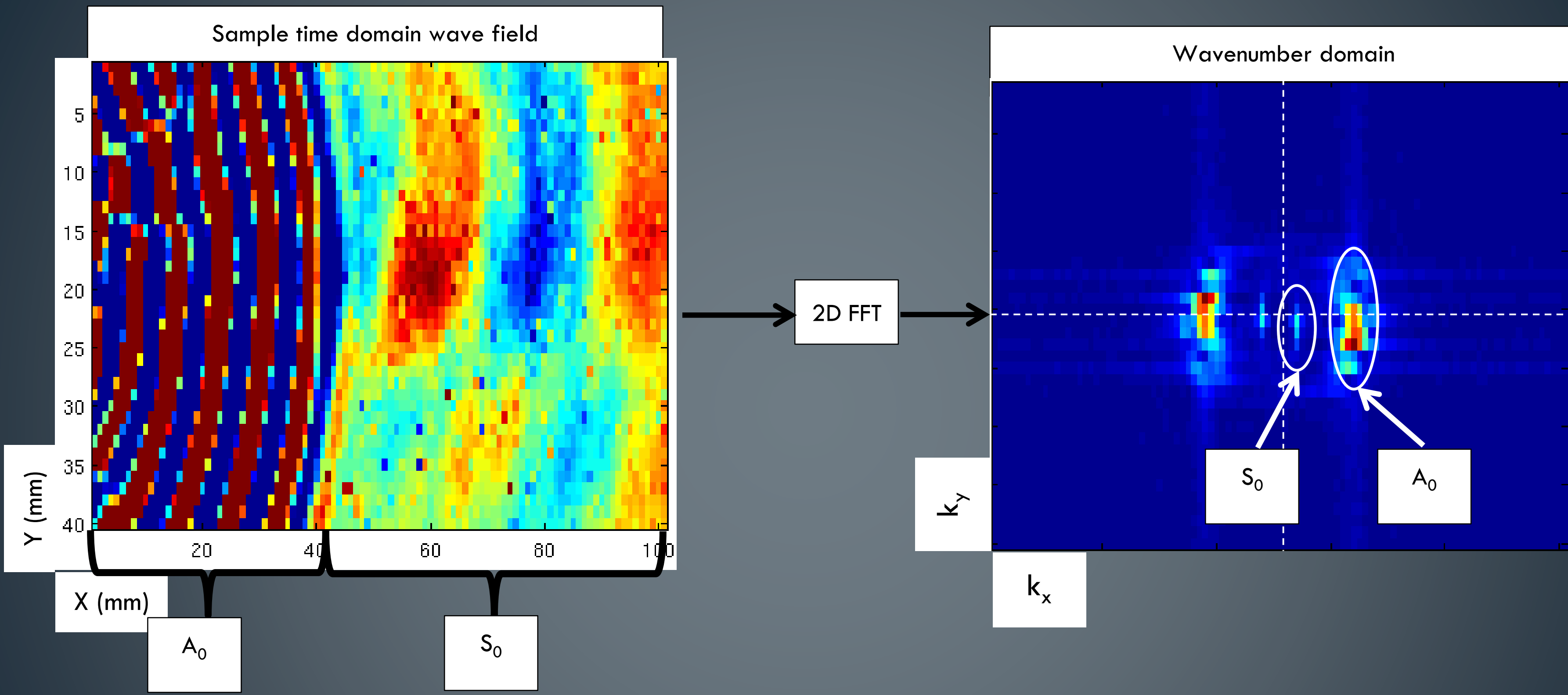
What are we detecting?

Nondestructive
Evaluation
Sciences Branch



Wavenumber Domain Analysis

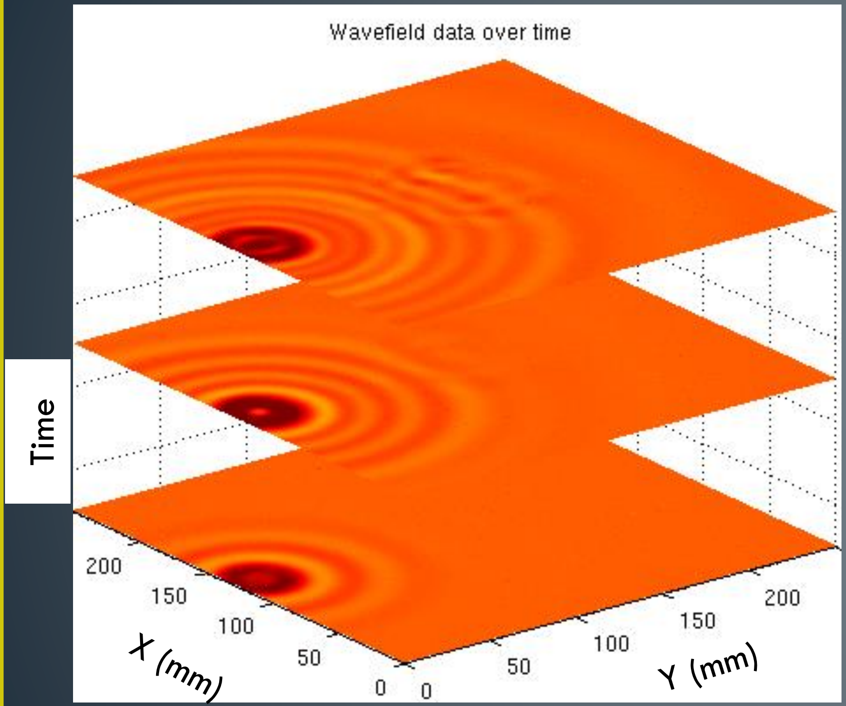
Nondestructive
Evaluation
Sciences Branch



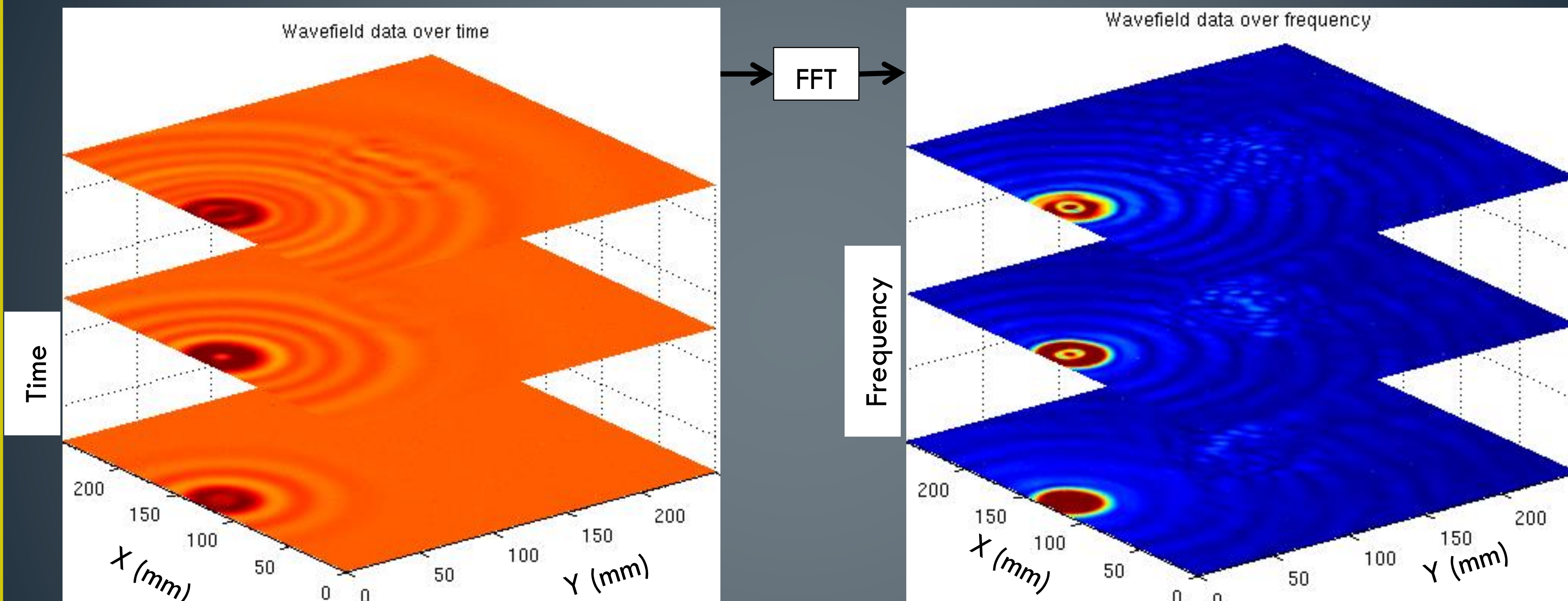
Any relationship between wavenumber and location is lost

Local wavenumber technique

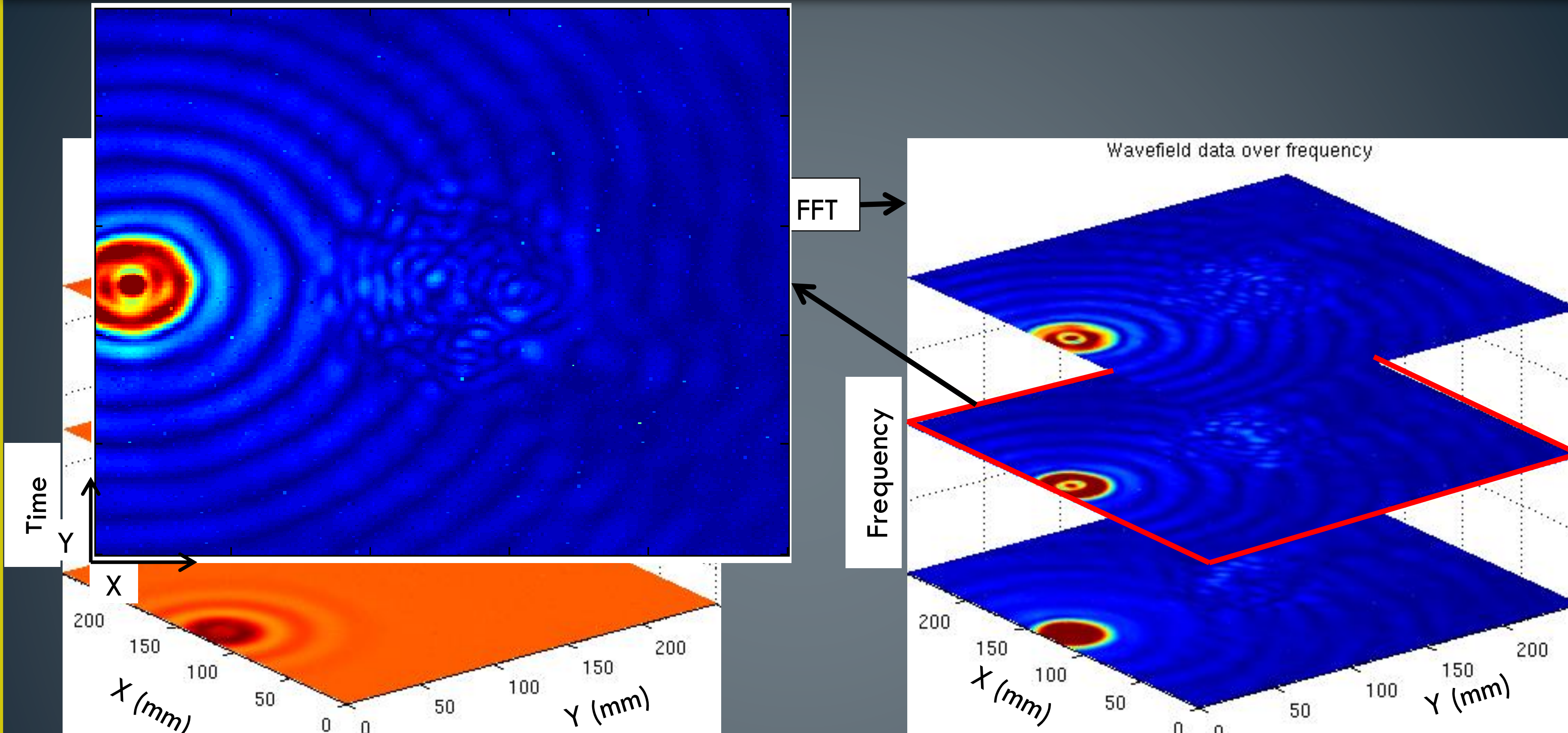
Nondestructive
Evaluation
Sciences Branch



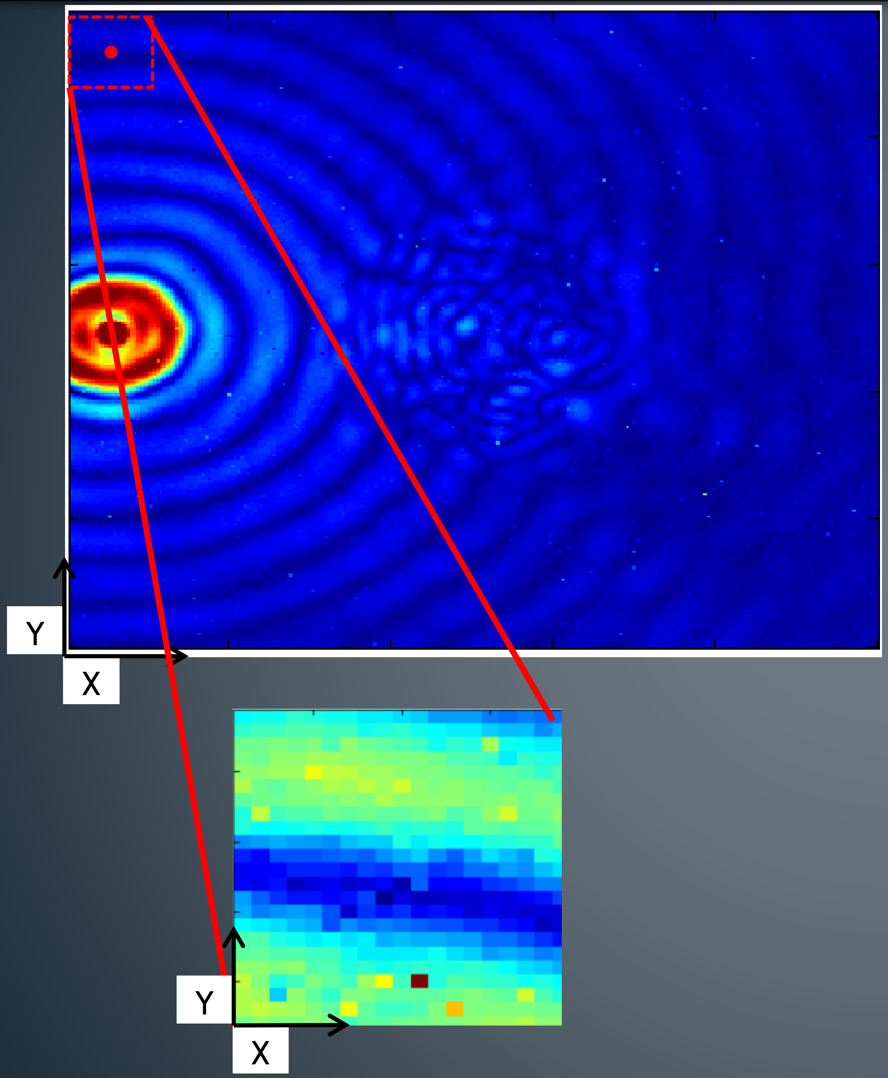
Local wavenumber technique



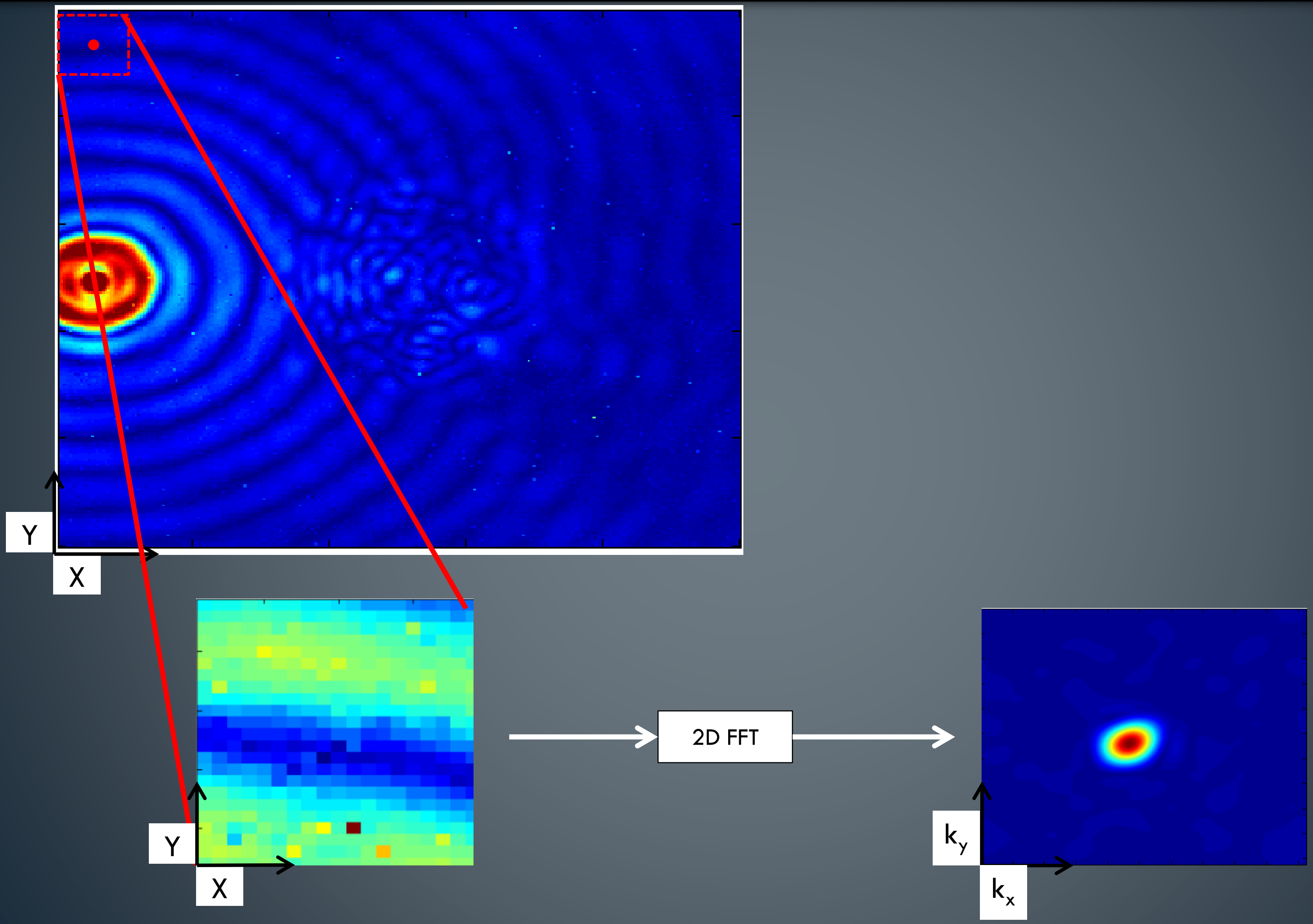
Local wavenumber technique



Local wavenumber technique

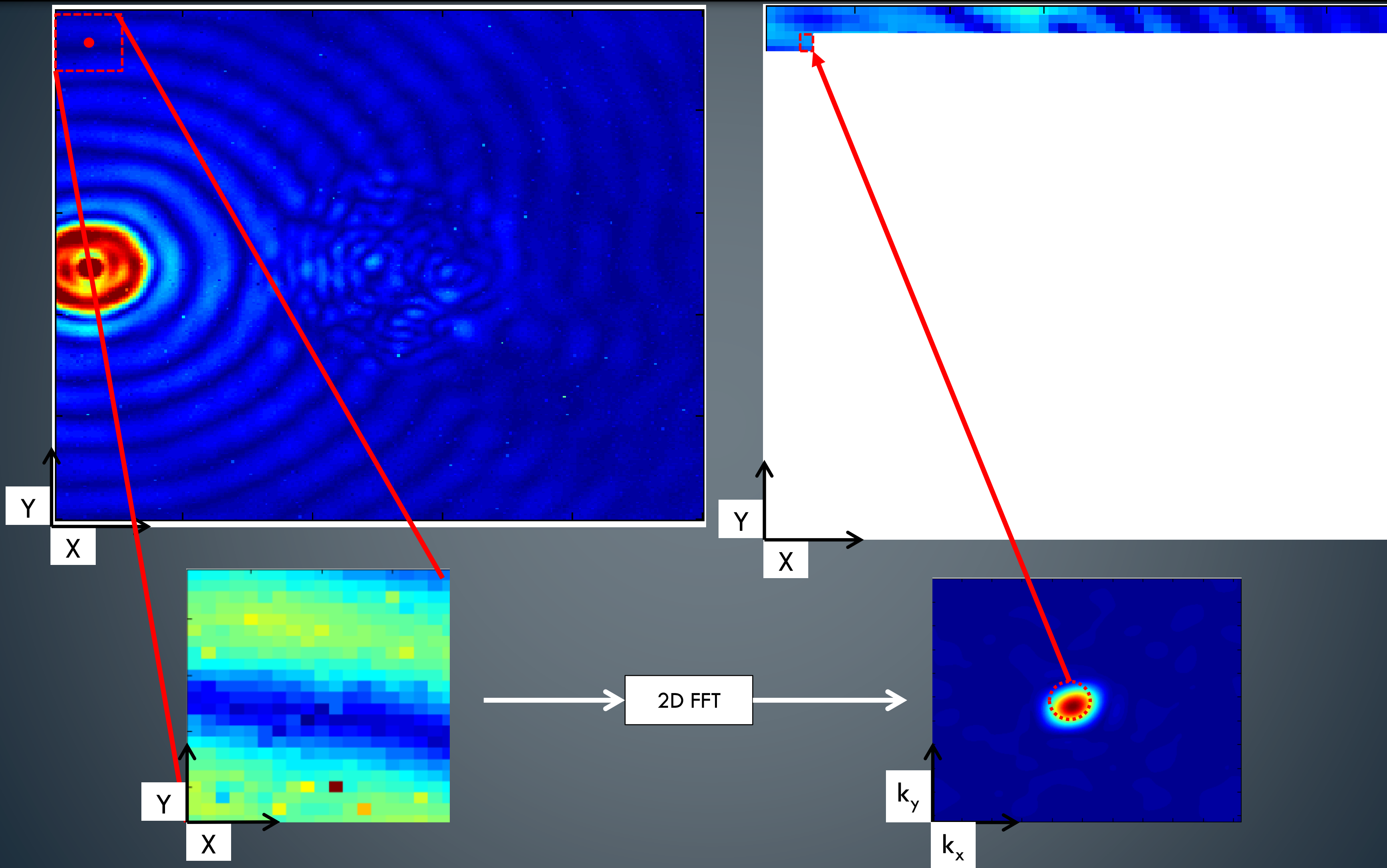


Local wavenumber technique

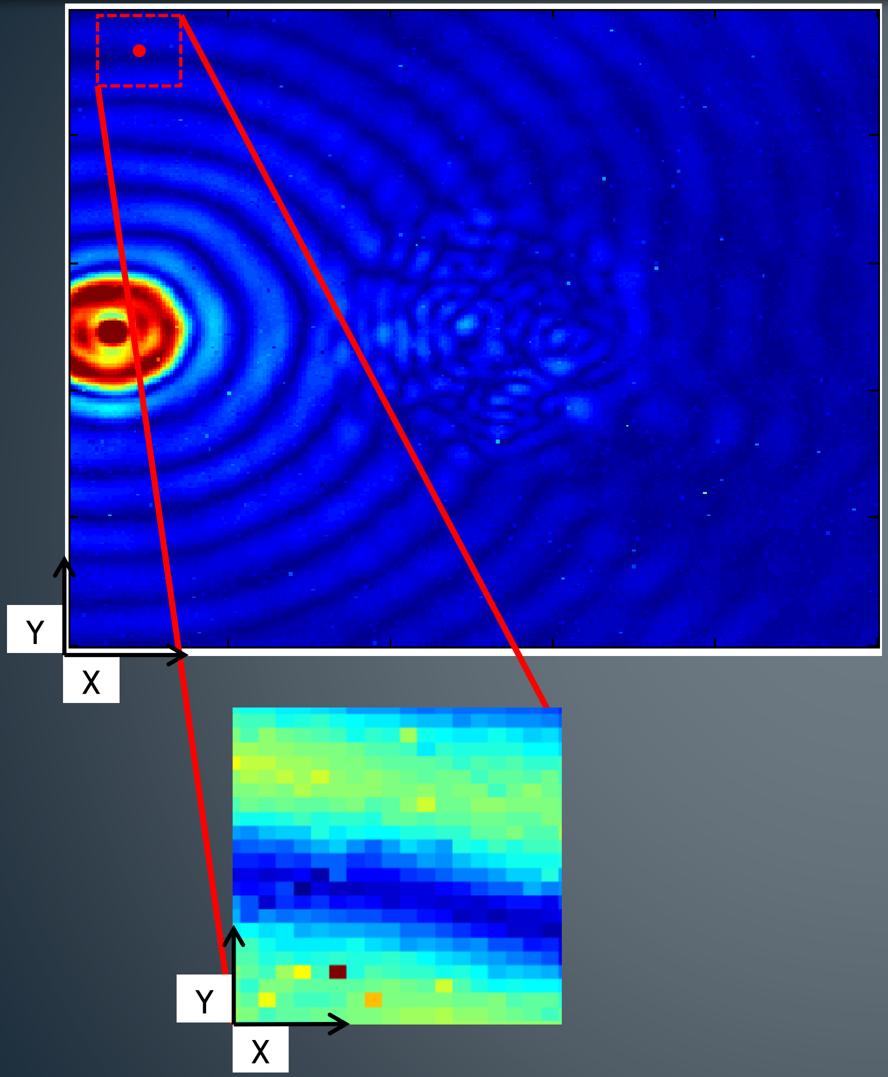


Local wavenumber technique

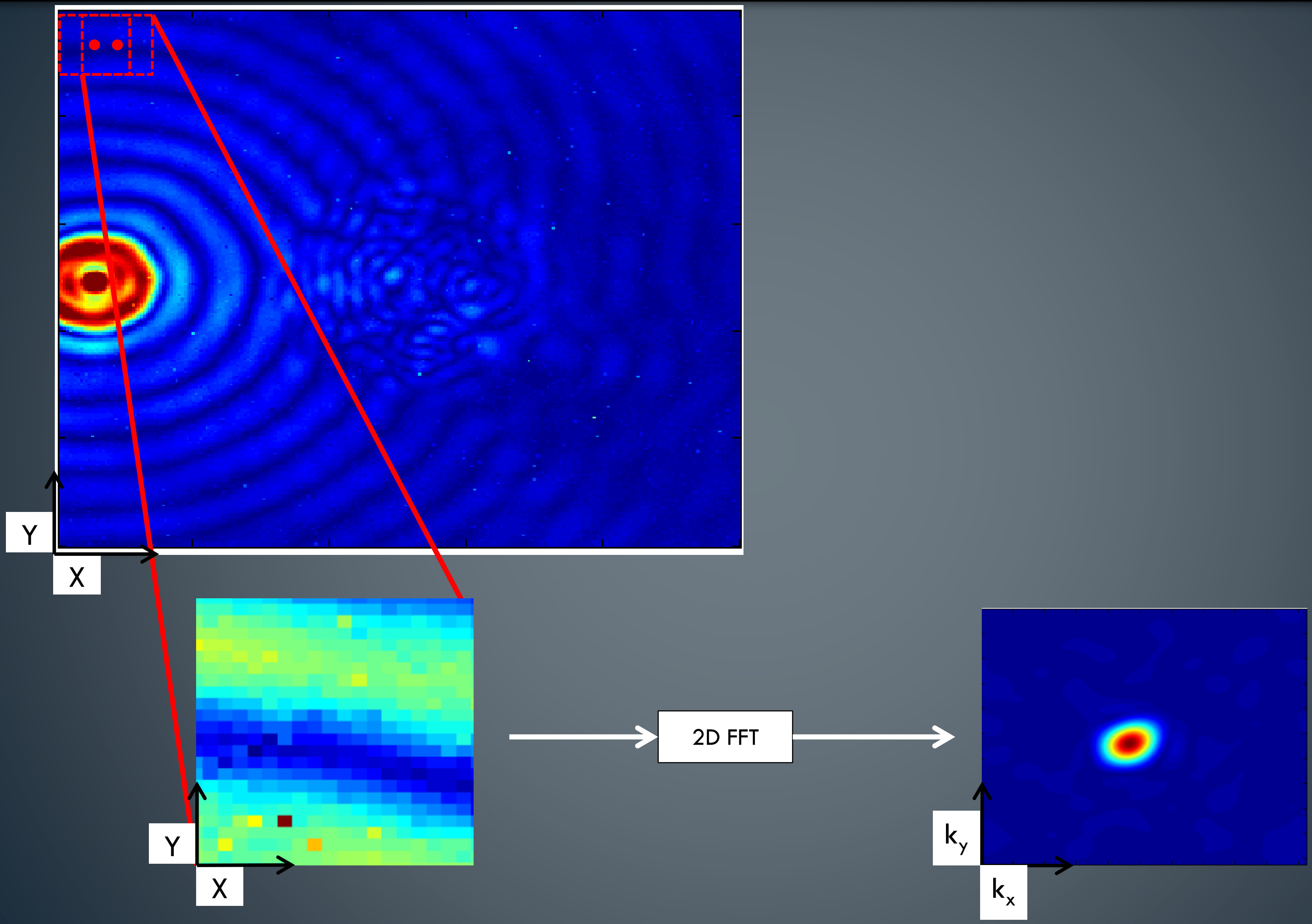
Nondestructive
Evaluation
Sciences Branch



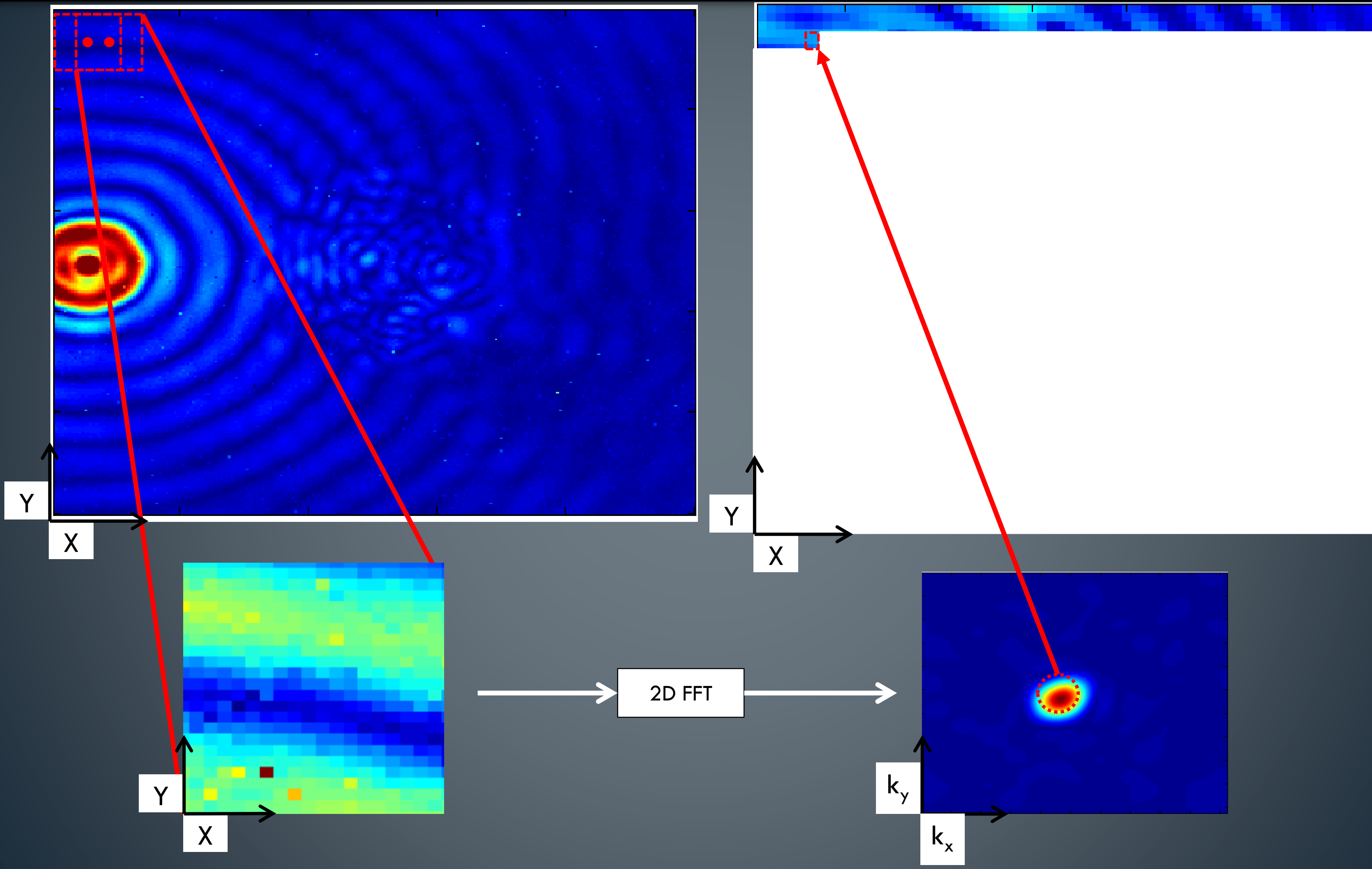
Local wavenumber technique



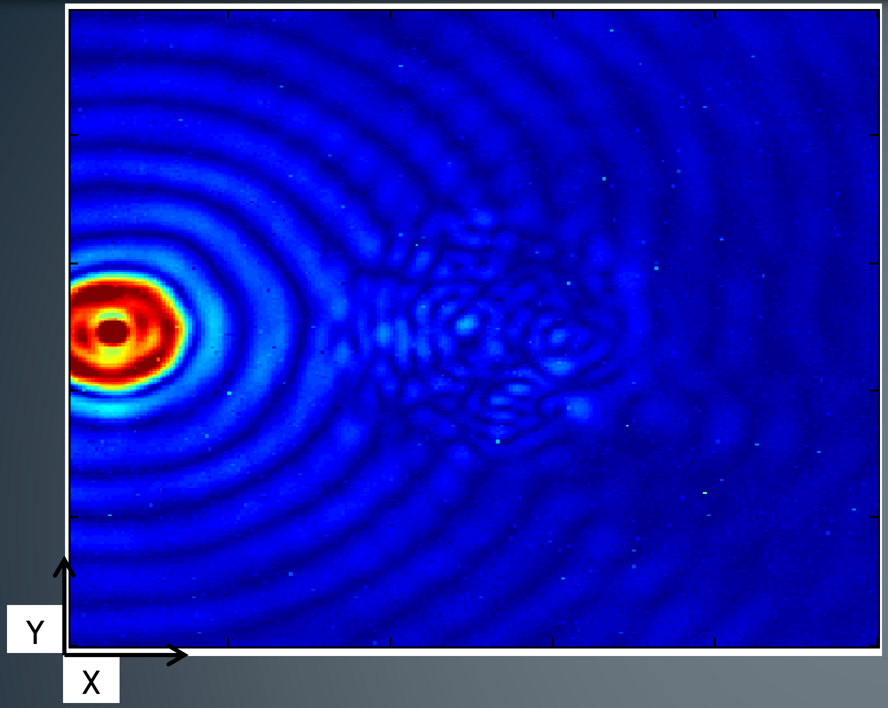
Local wavenumber technique

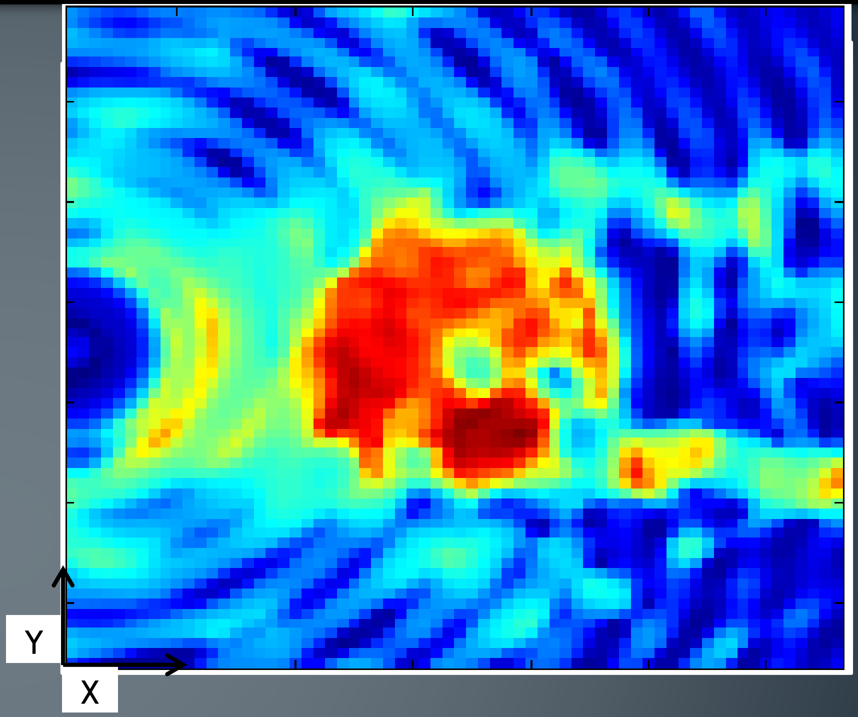


Local wavenumber technique

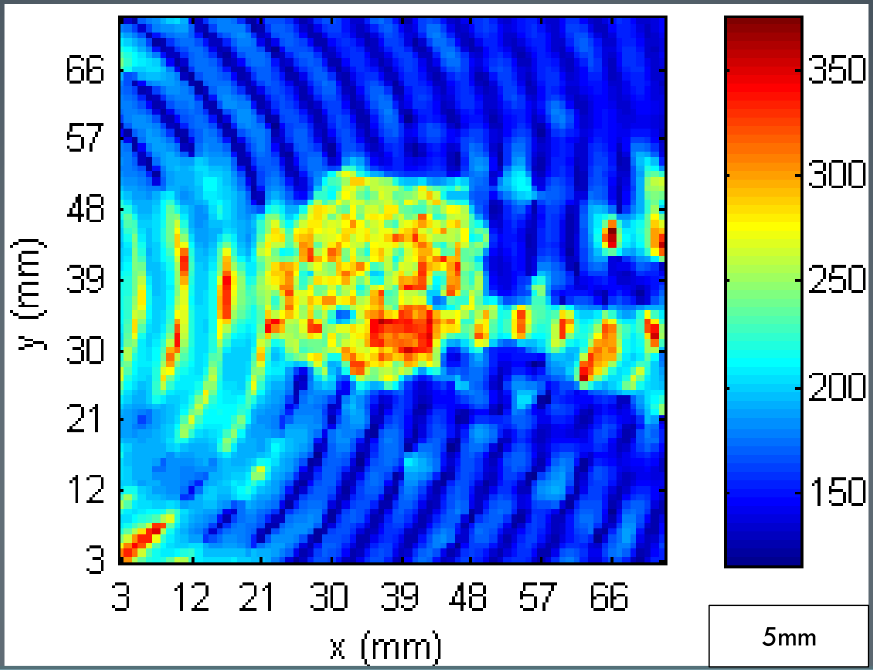


Local wavenumber technique





Window size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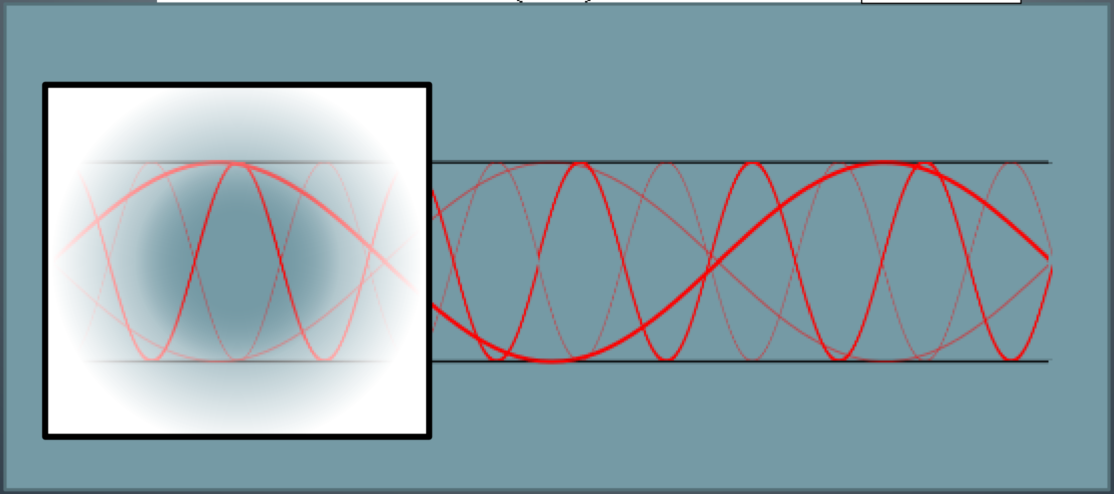

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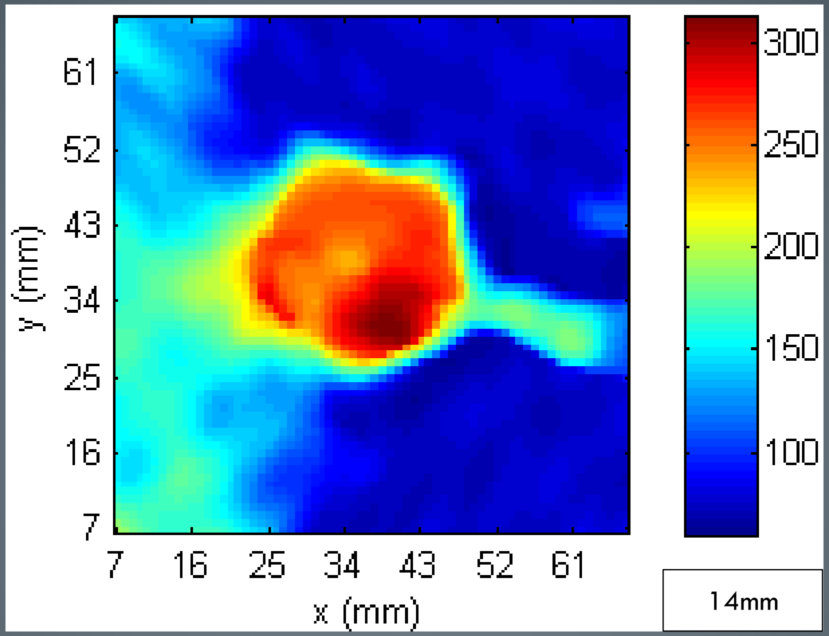
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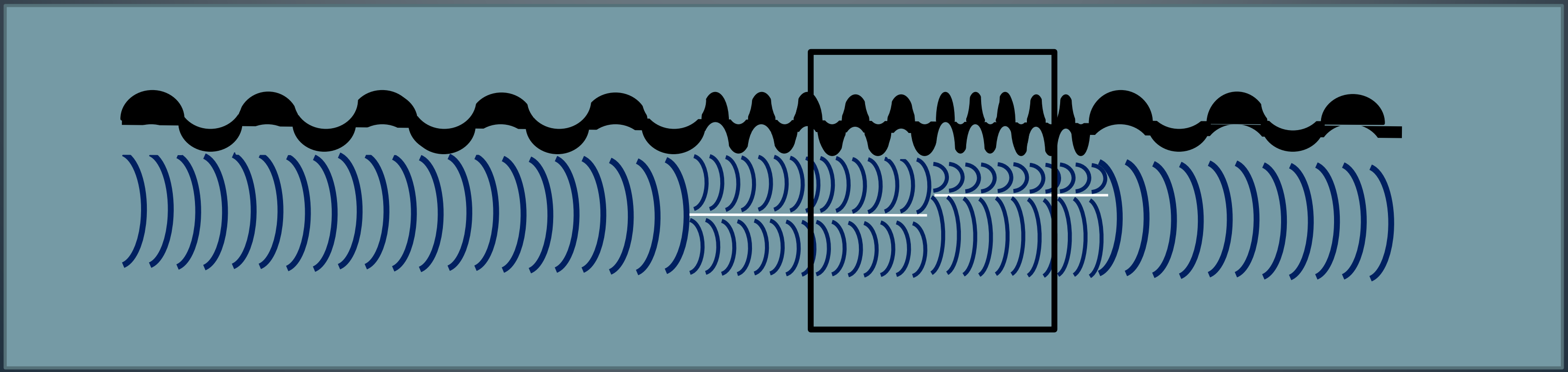

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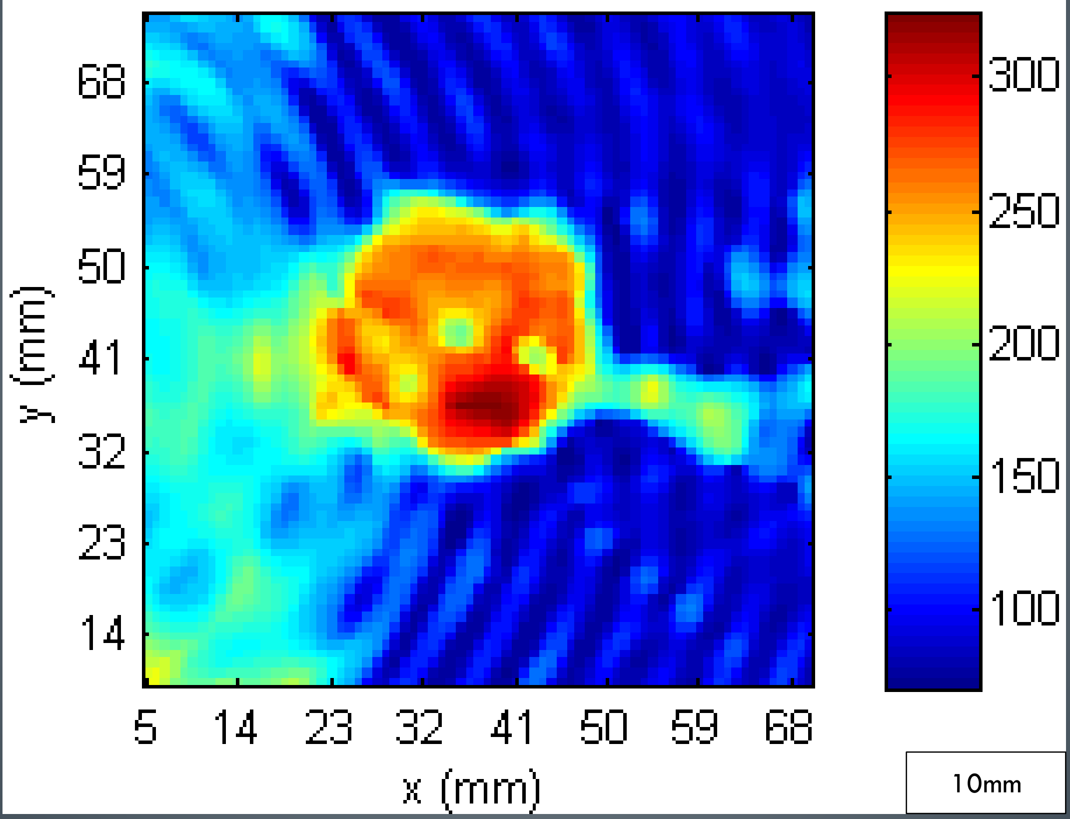
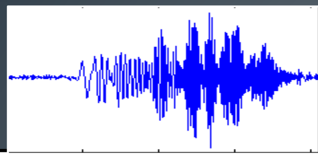
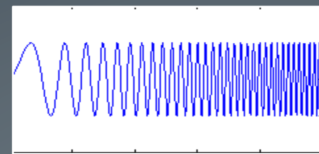


10mm

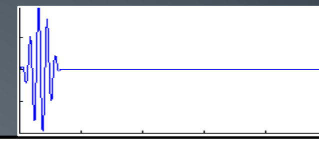
Dechirp process



Data recorded using chirp excitation



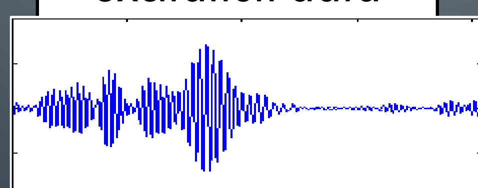
Chirp Excitation Signal



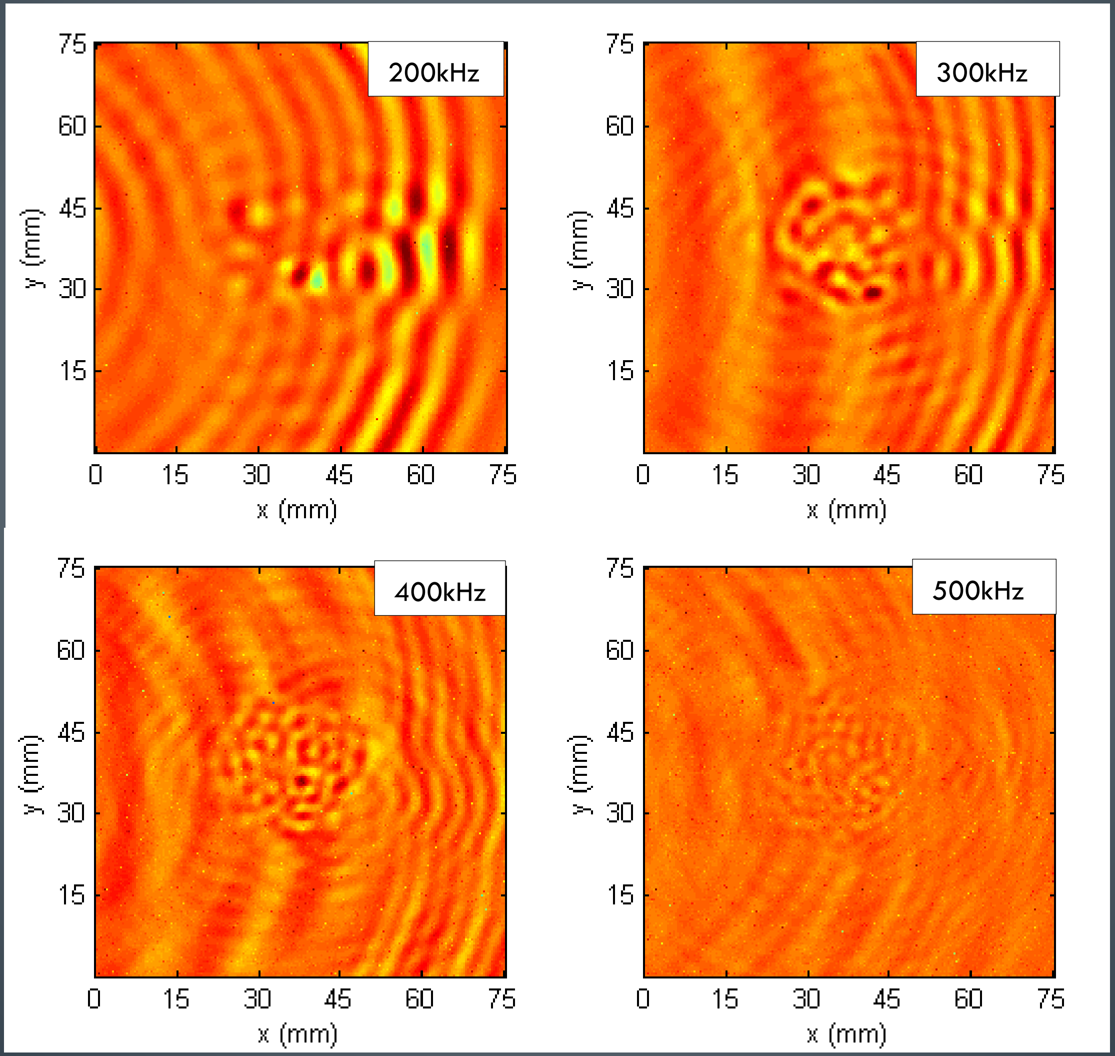
Desired single frequency signals

$$u(x,y,t) = \mathcal{F}^{-1}\left[\frac{\mathcal{F}(R_c(x,y,t))}{\mathcal{F}(S_c(x,y,t))} * \mathcal{F}(S_d(x,y,t))\right]$$

Single frequency excitation data



Differences in frequencies: Wavefields



Differences in frequencies: Wavenumber

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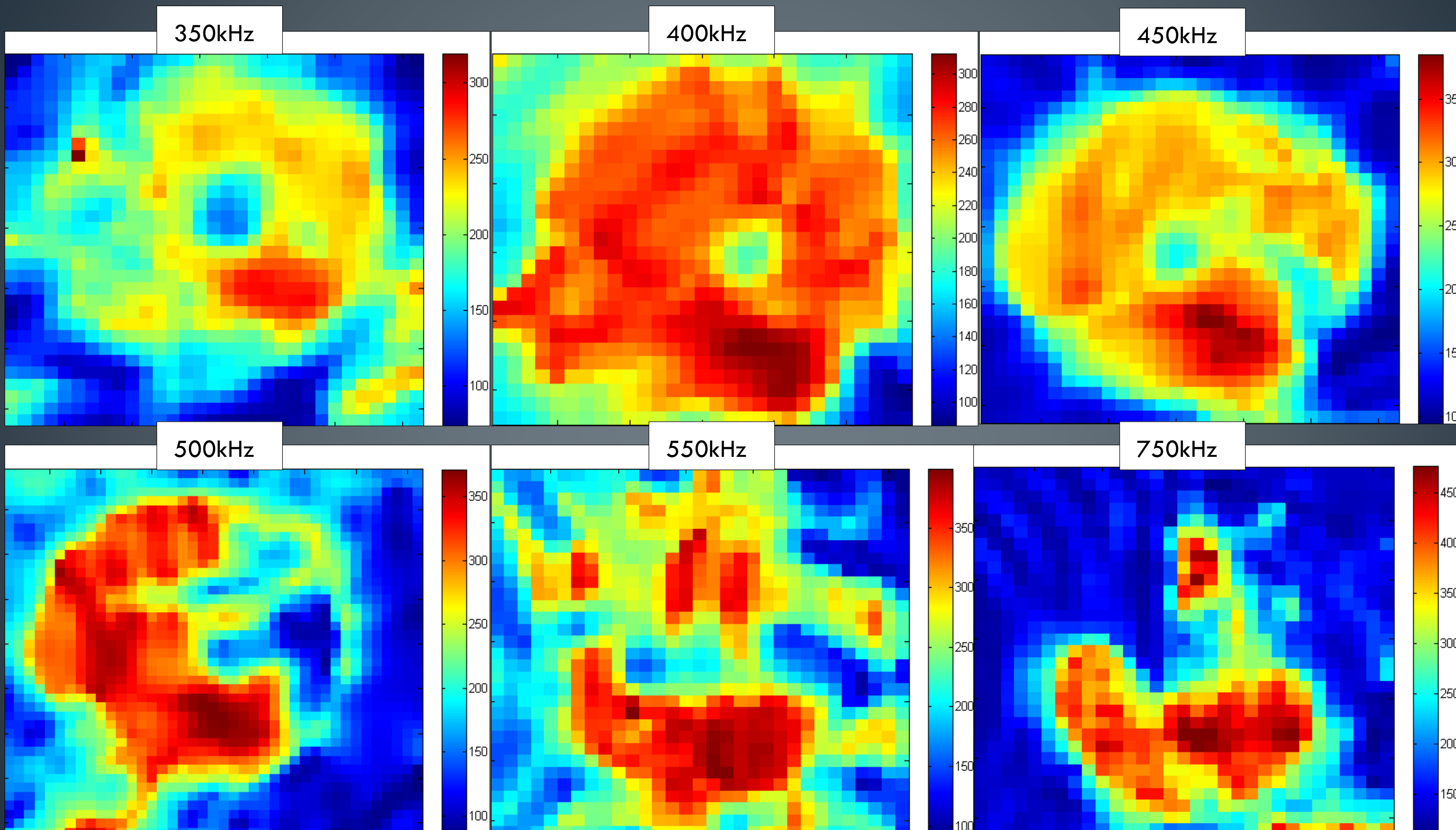
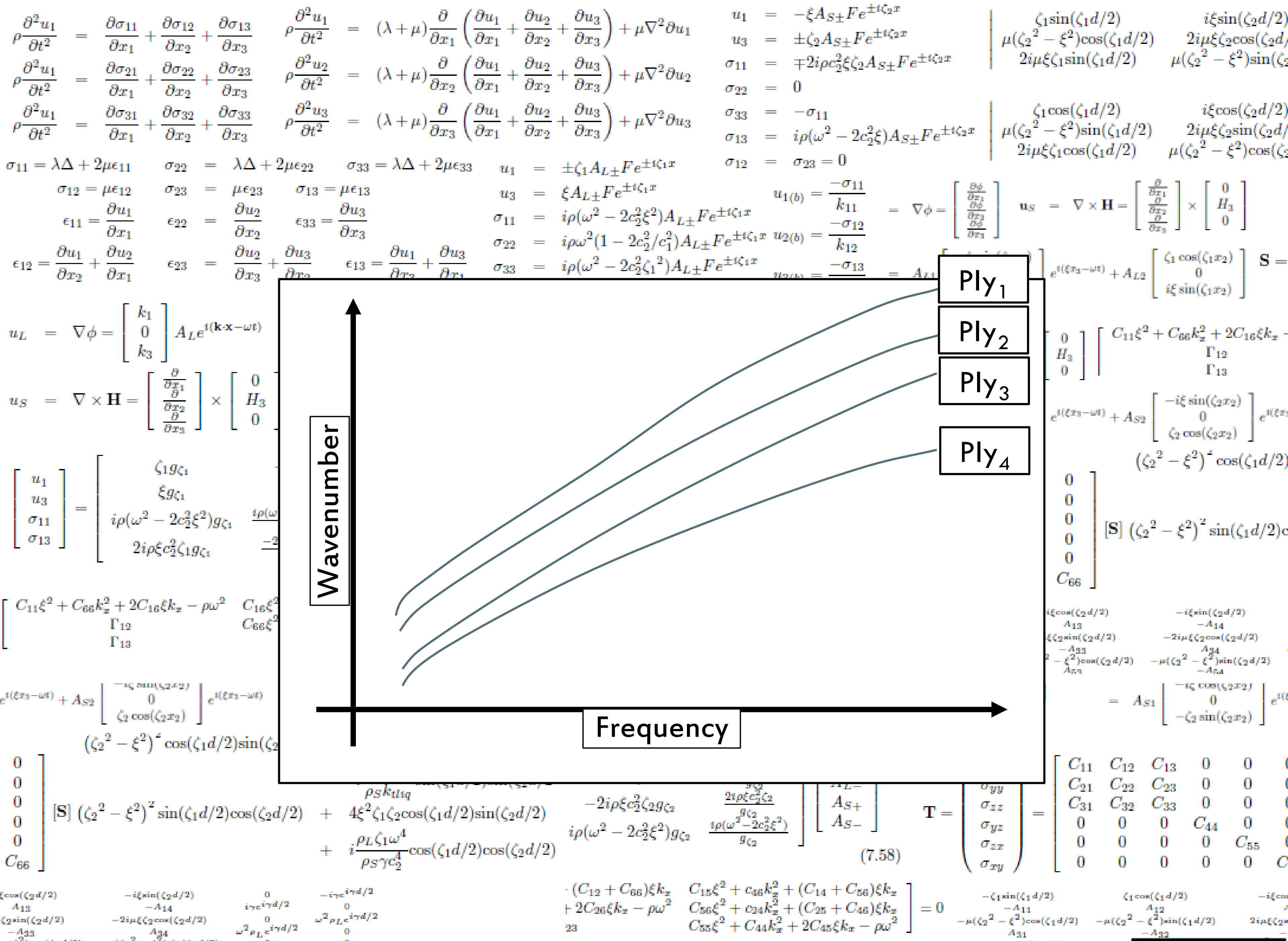
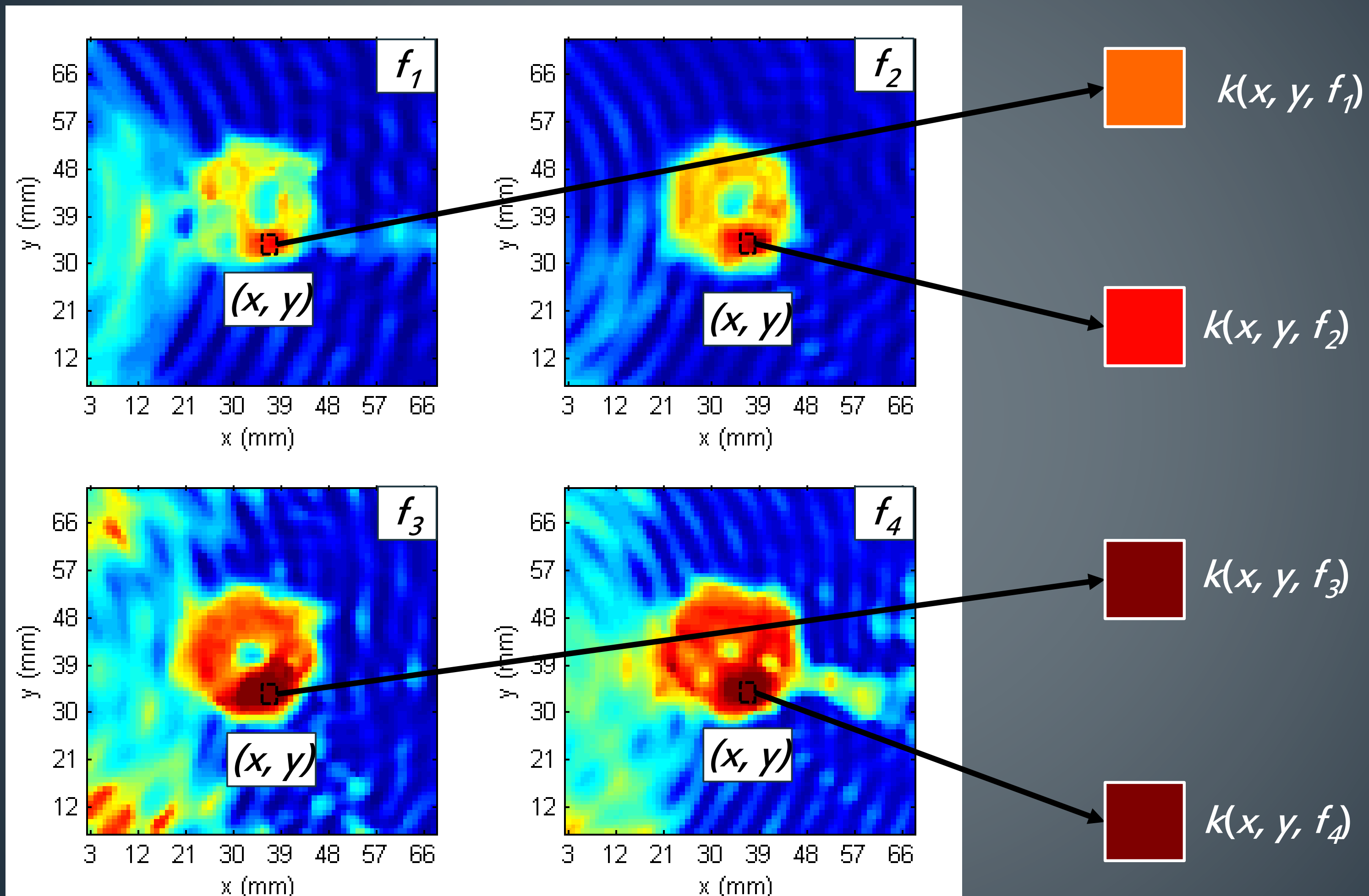


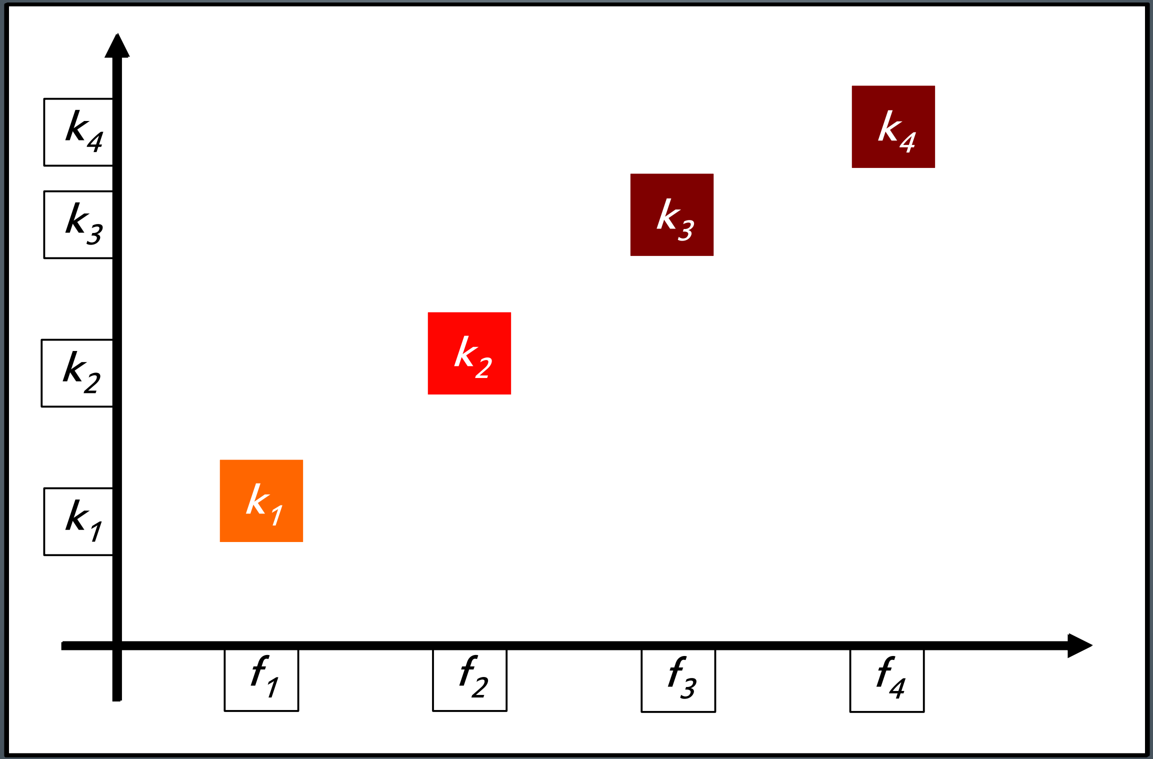


Next: Curve correlation

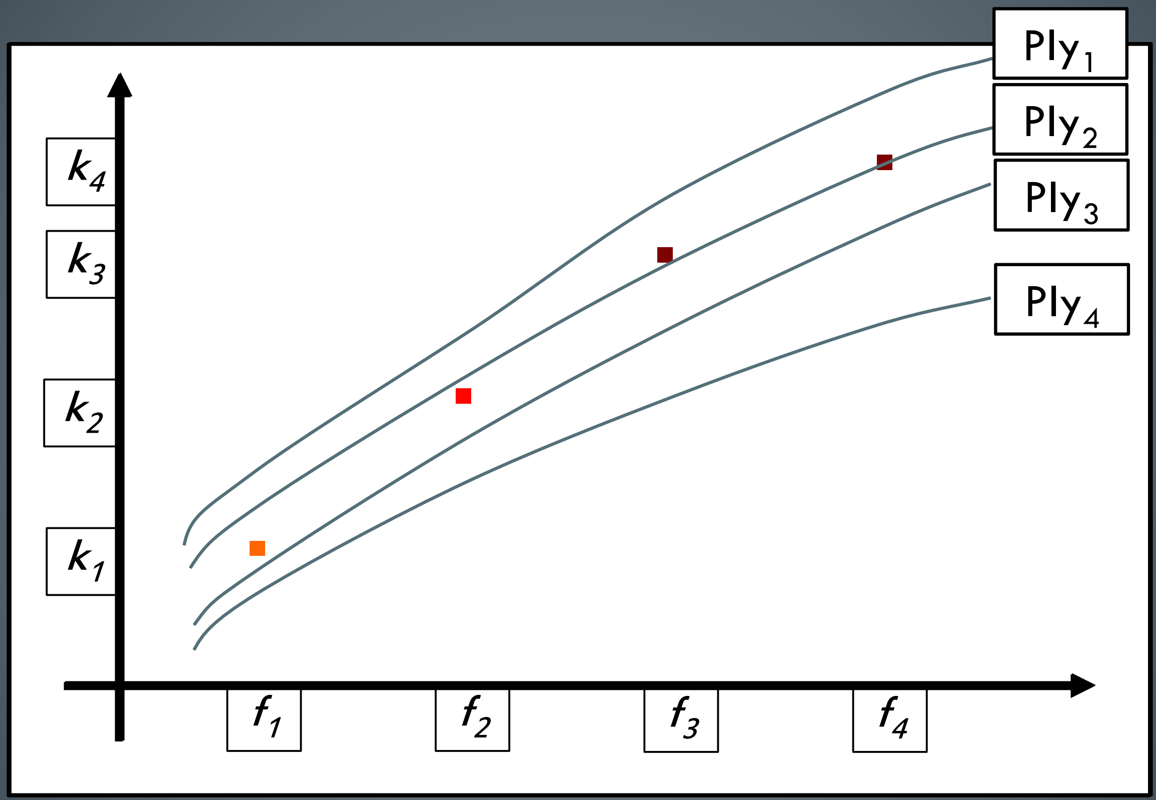
Multi-frequency wavenumber-ply correlation



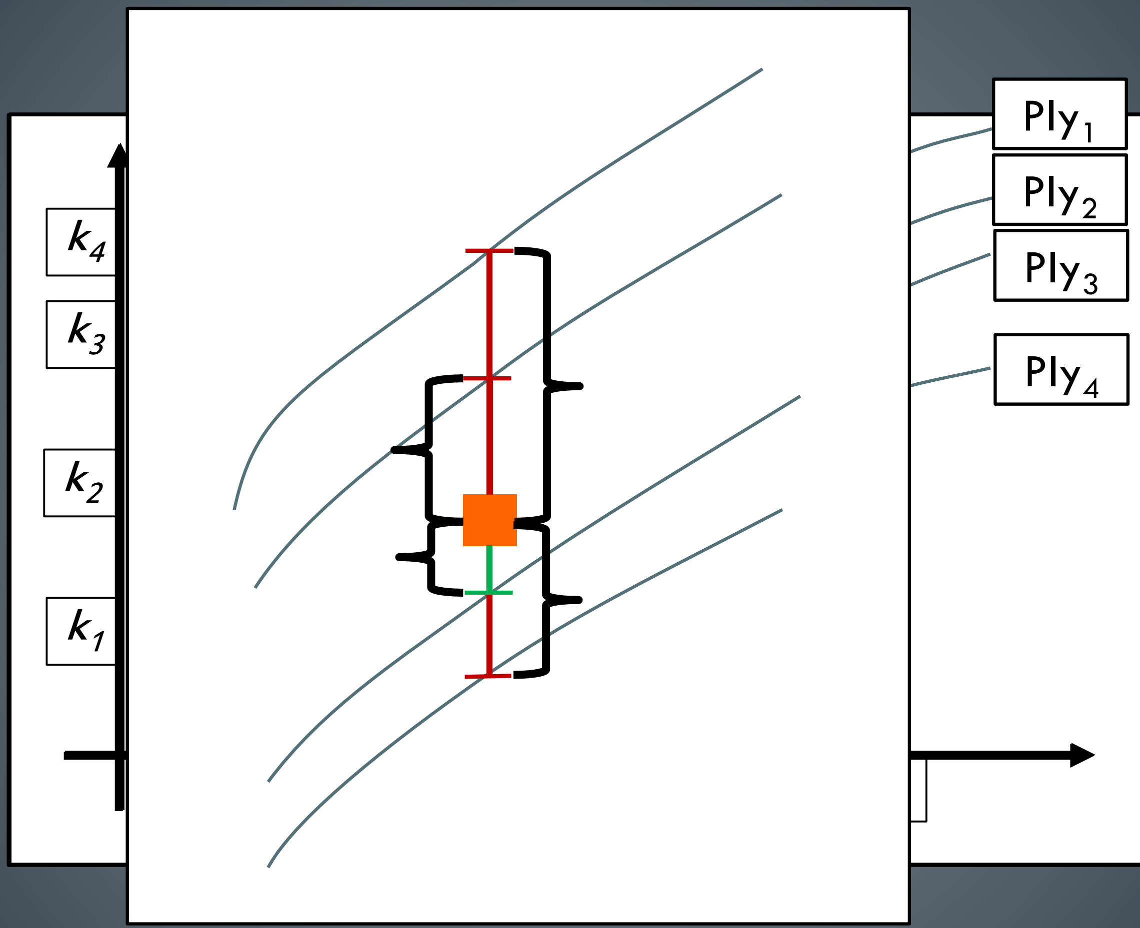
Multi-frequency wavenumber-ply correlation



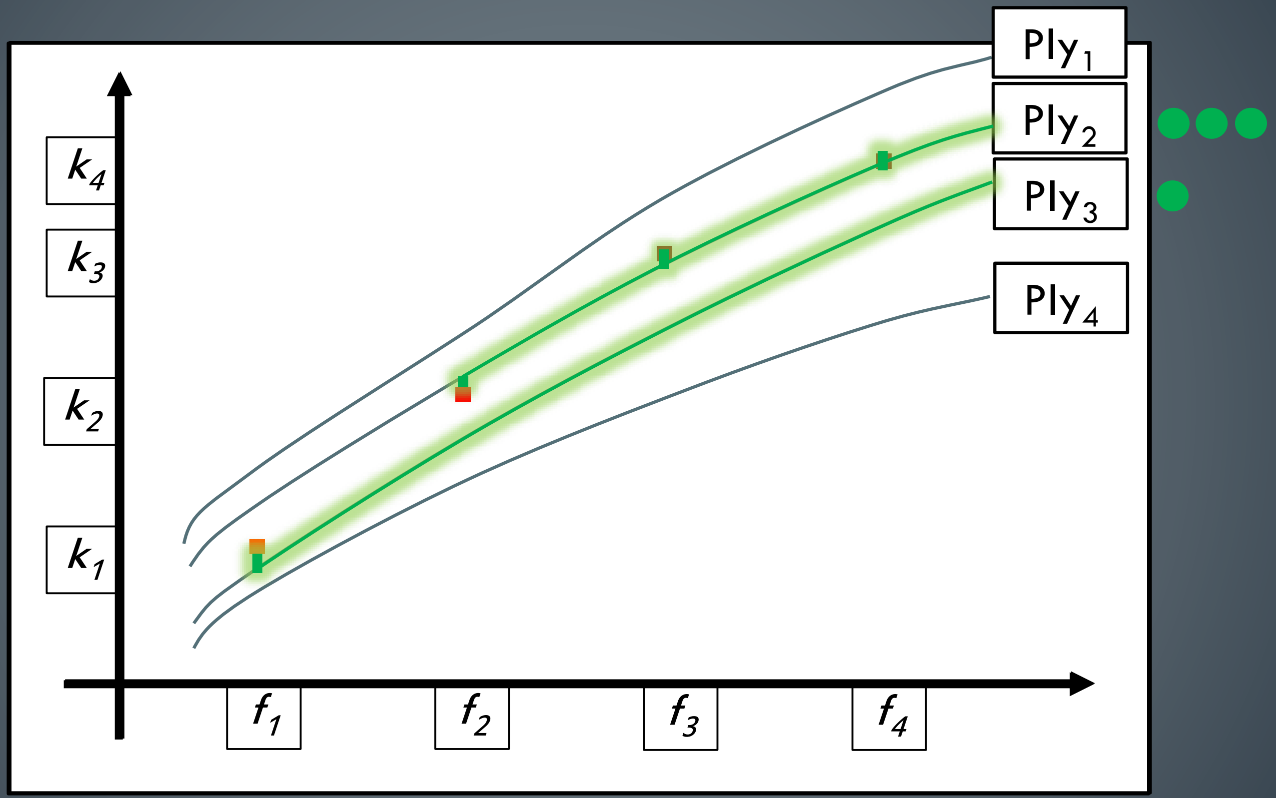
Multi-frequency wavenumber-ply correlation



Multi-frequency wavenumber-ply correlation

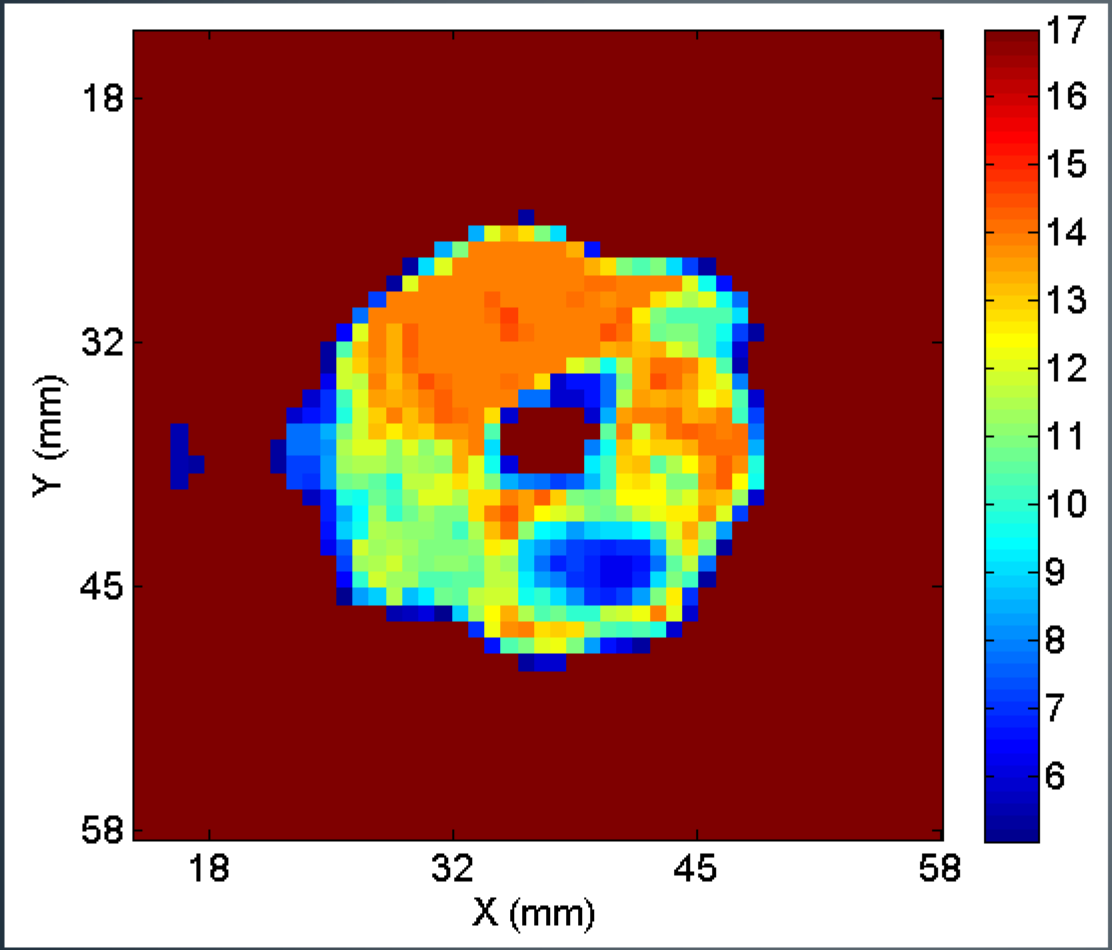


Multi-frequency wavenumber-ply correlation



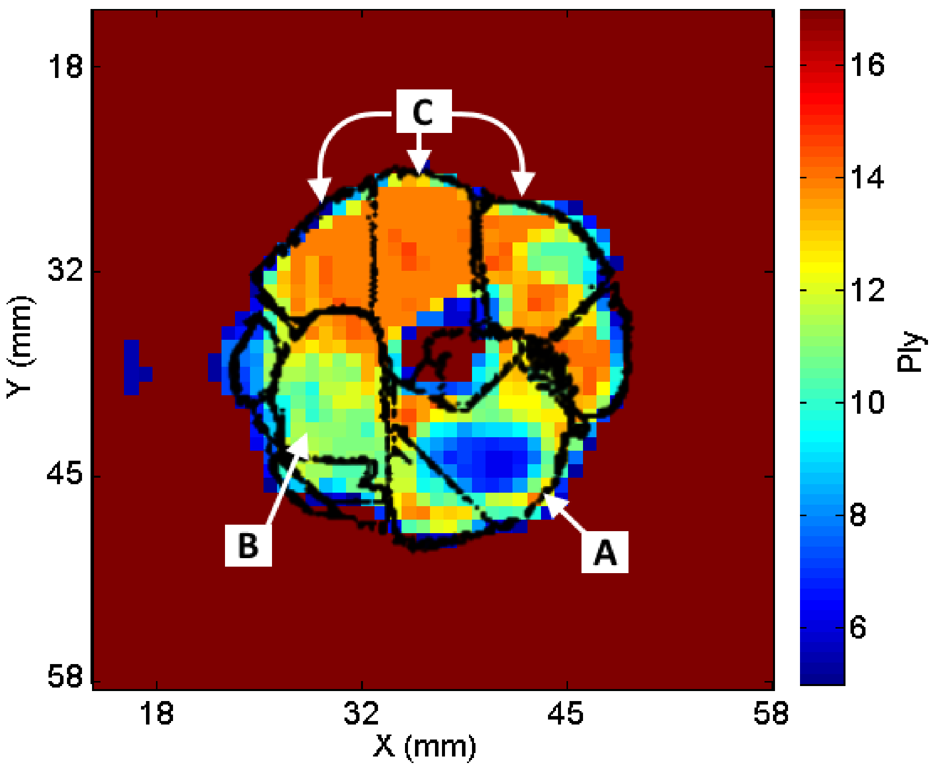
$$\text{Ply}(x, y) \approx \text{Ply}_2$$

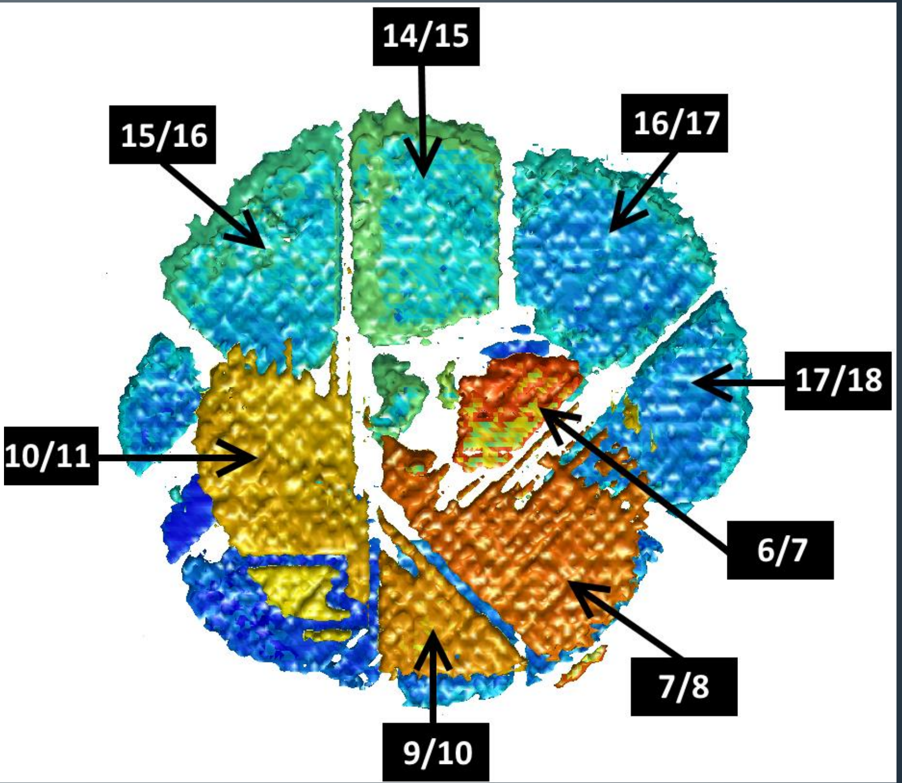
Ply correlation results



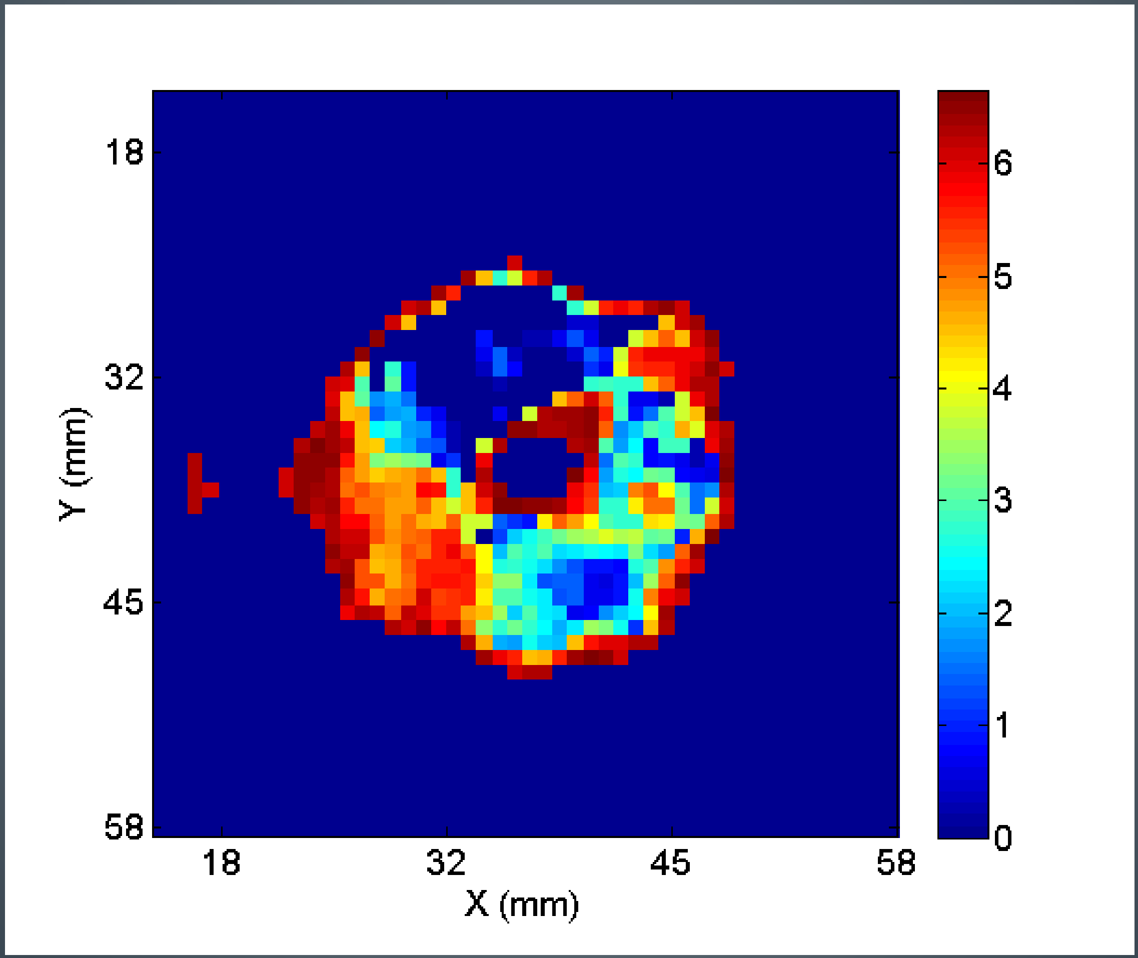
- Correlation frequency range: 300kHz-400kHz in 5kHz steps
- 10mm window
- 0.3mm spatial resolution
- 20MHz sampling rate

Ply correlation results

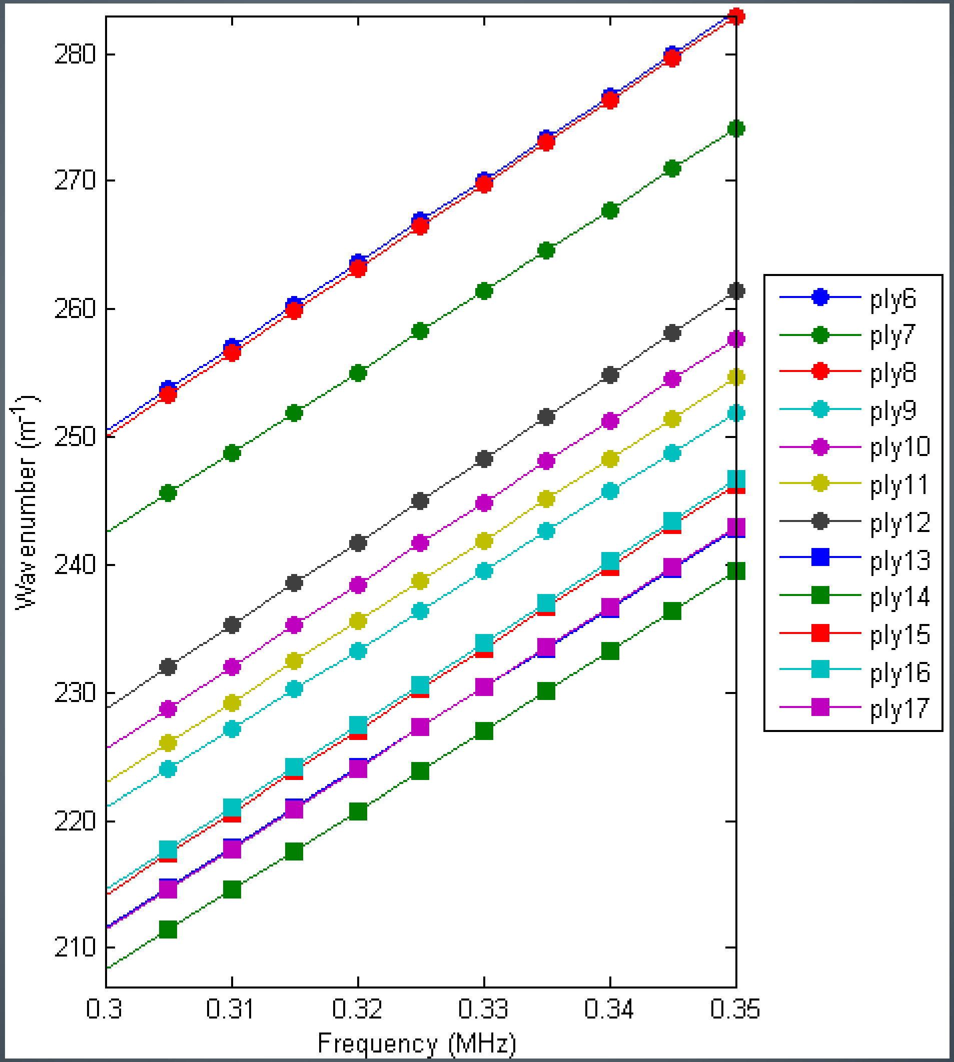




Sources of error: standard deviation



Sources of error: dispersion curves



Conclusions

- The local wavenumber technique is capable of very accurate determination of the shape and size of interlamina damage in composite panels, especially when considering multiple frequencies
- Using multi-frequency wavenumber-ply correlation can determine the depth location of damage in many instances, but struggles with deeper and smaller delaminations.
- Future research will be conducted to improve this methodology using wave domain filtering, better dispersion curve generation, and more robust correlation methods.

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Nondestructive
Evaluation
Sciences Branch

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