Rapid grain orientation imaging using spatially resolved acoustic microscopy (SRAS)

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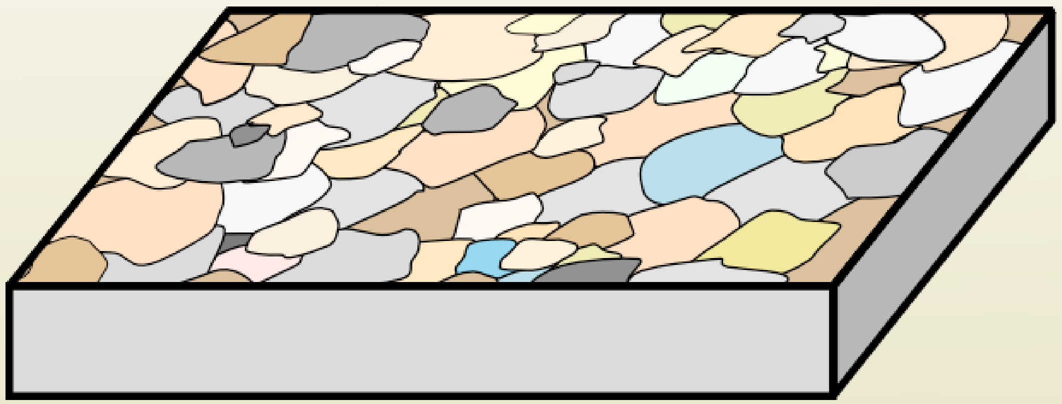
Aim: to image material microstructure

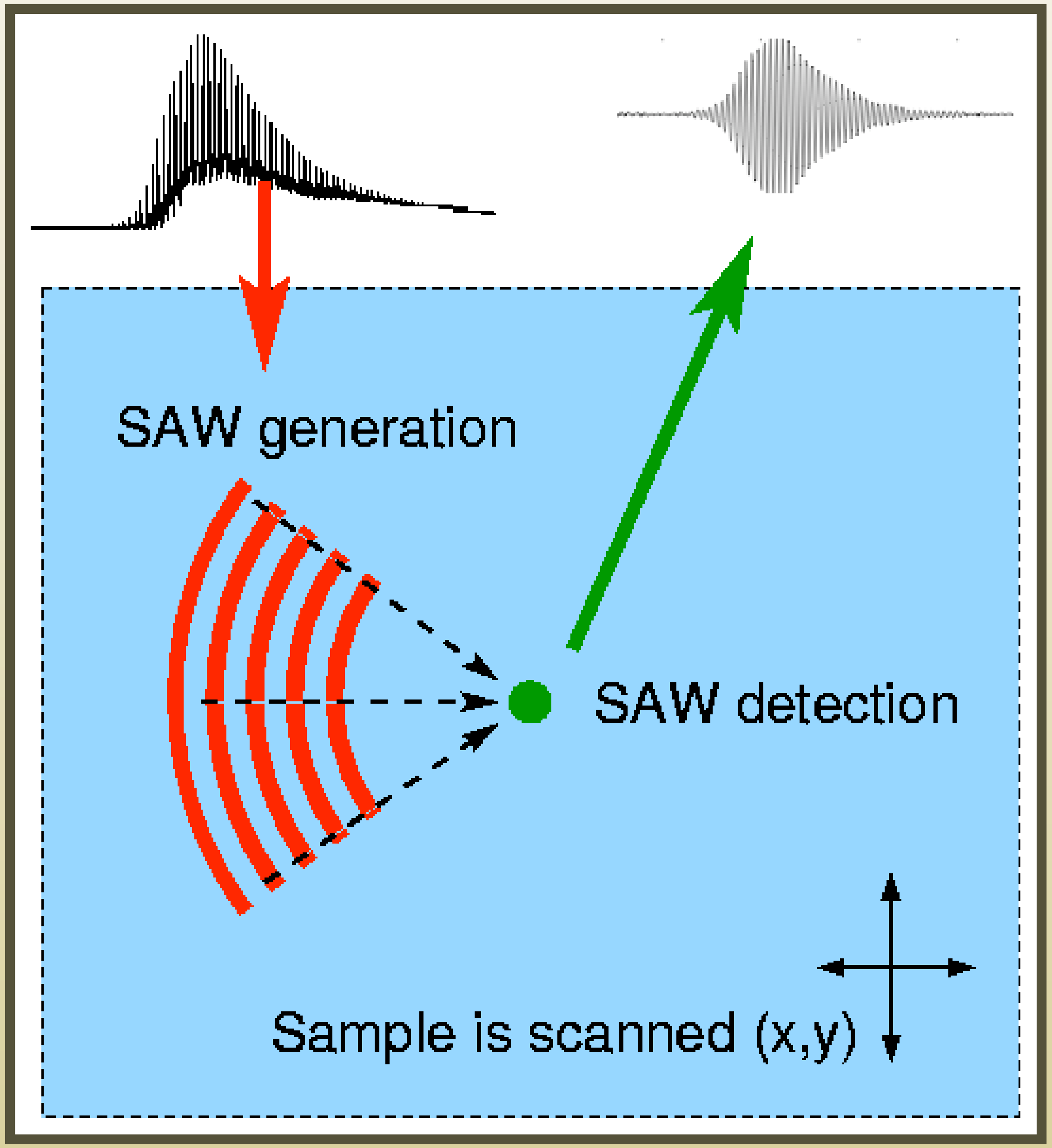
We would like to image the grain structure of industrially-relevant materials - titanium, aluminium etc.



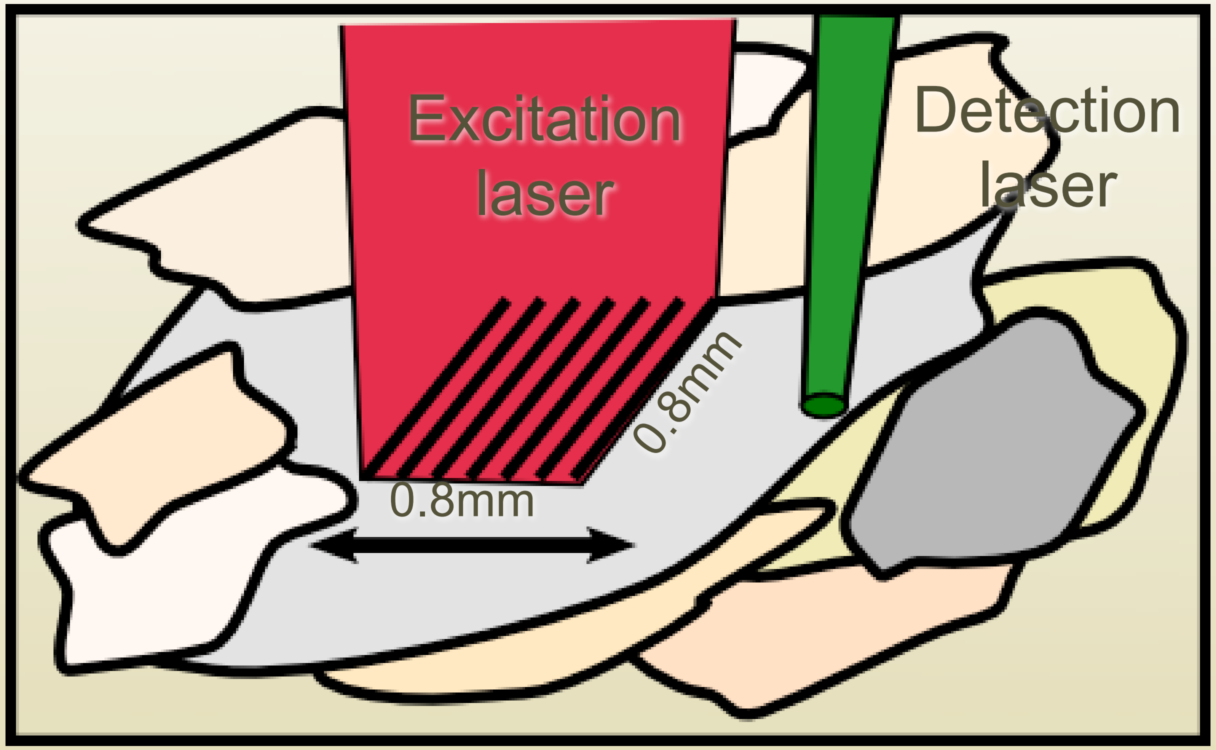
- Metallurgists are interested in grain structure:
  - Degree of randomness, of both size and orientation
  - Clusters of grains all oriented in the same direction
  - Likely areas of fatigue failure
- The method should be:
  - "Fast", completely non-destructive, and quantitative
- Use SAW phase velocity - which varies with grain orientation - as contrast mechanism

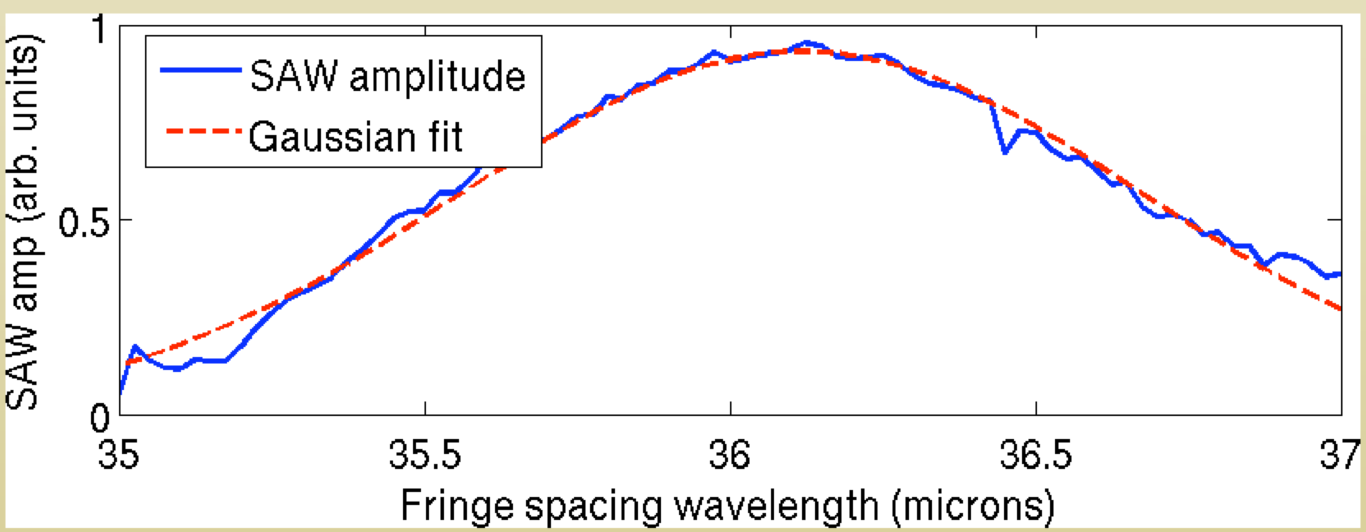
How we generate SAWs with the O-SAM

- Pulsed laser source
  - Fundamental frequency 82MHz
  - Repetition rate ~few kHz
- Spread out the light
  - Multiple lines
    - lower power density
    - no damage
- Focus the SAWs
  - Higher amplitudes
    - easier and faster detection
- Multiple line source:
  - **Generation efficiency depends on how well you match the line spacing to the SAW wavelength**



SRAS: spatially resolved acoustic spectroscopy

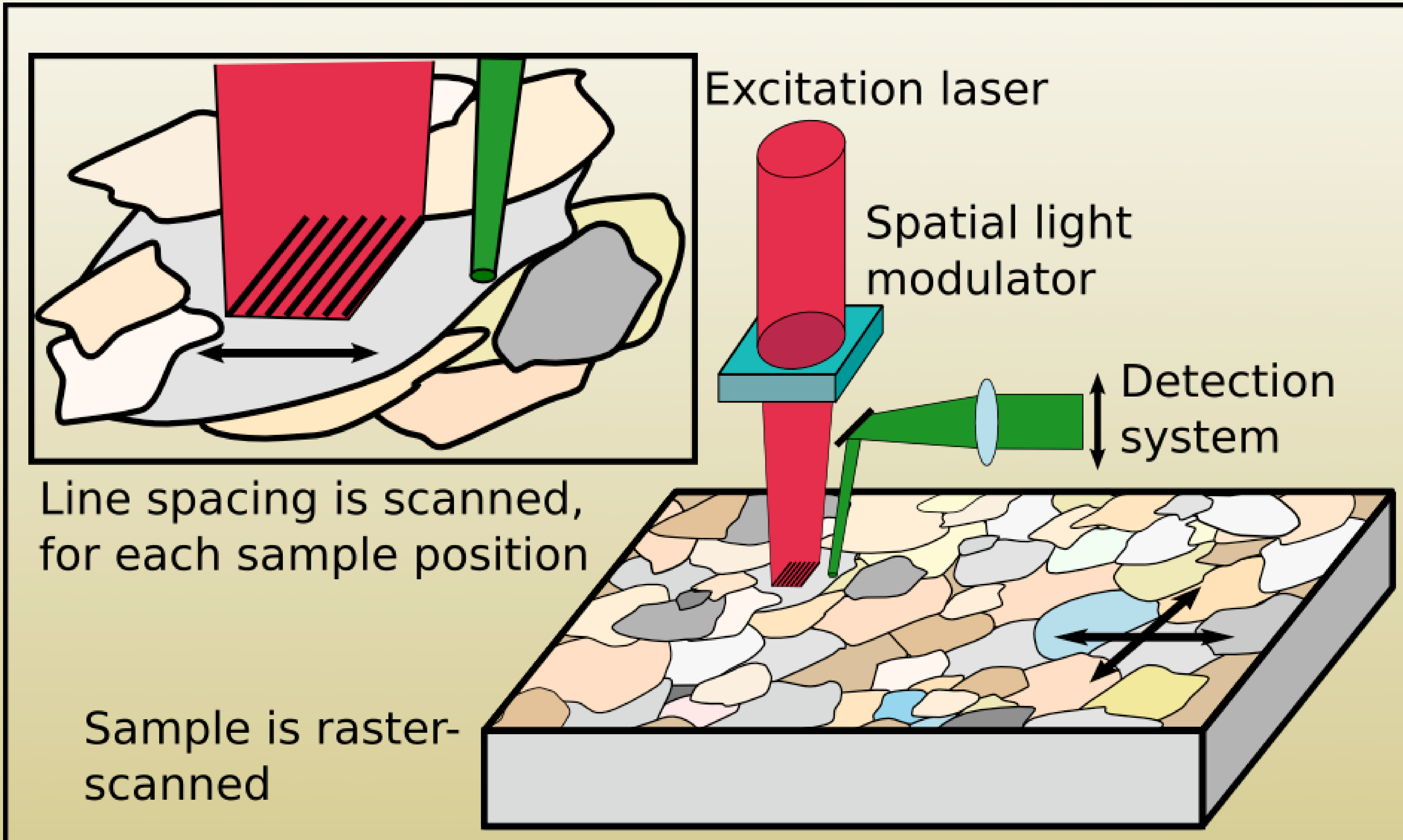




- Fixed excitation frequency (82MHz)
- To find phase velocity of material in the area of excitation, we vary the fringe spacing of the excitation source
- When the fringe spacing matches the SAW wavelength, we get the best signal

$$v = f\lambda$$

System schematic

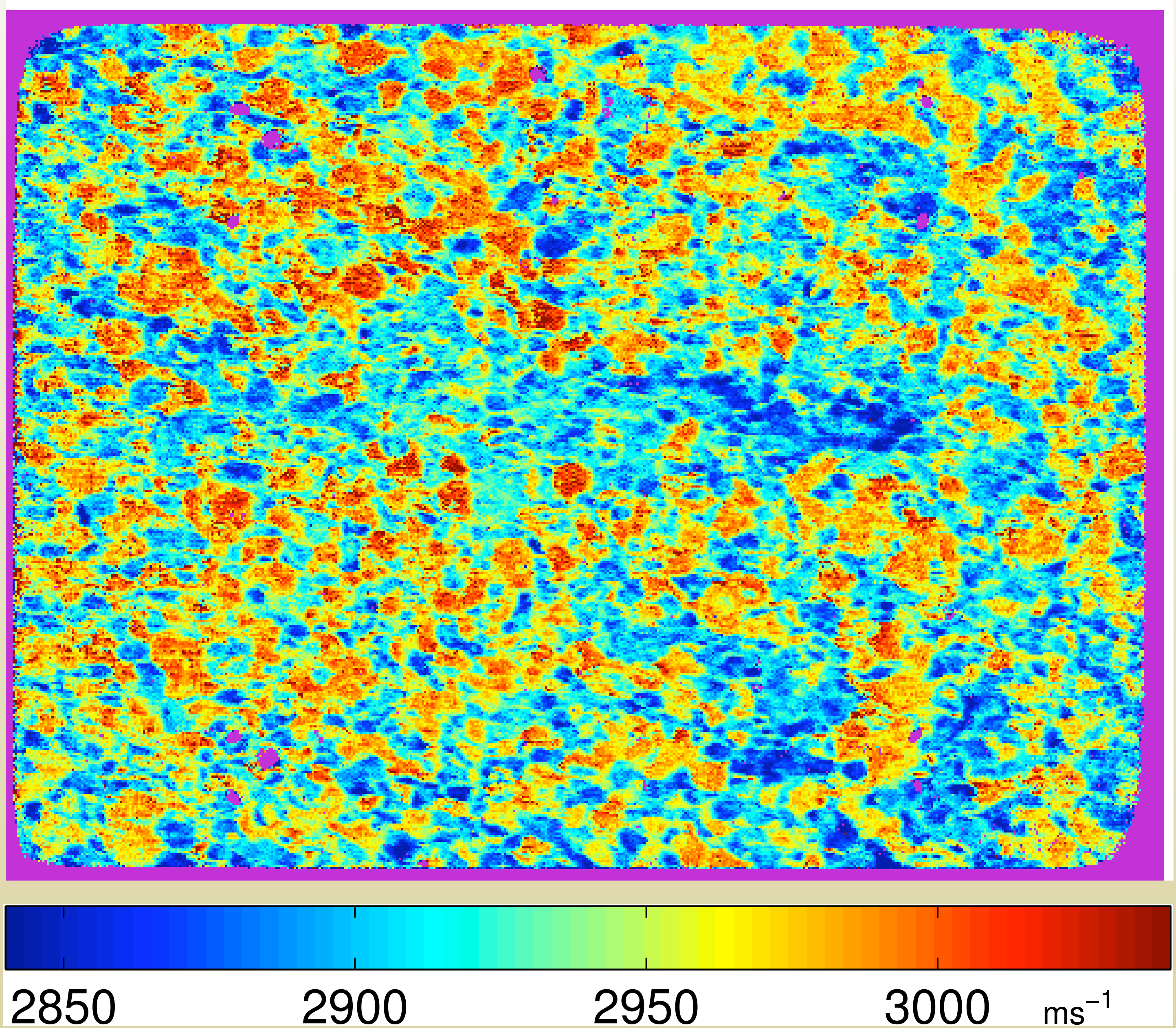


SRAS capabilities

- Lateral (spatial) resolution determined by SLM image size
  - Current spatial resolution is approximately 0.4mm
- Relative velocity resolution determined by signal/noise and number of fringes, if curve-fitting is used
  - On a good sample, the best velocity resolution is $\pm 1.5ms^{-1}$ (approximately 0.03%)
- Absolute velocity certainty is determined by how accurately the SLM image size is known
  - Can give systemmatic error of a few percent
- Typical scanning speed: ~100 points/sec

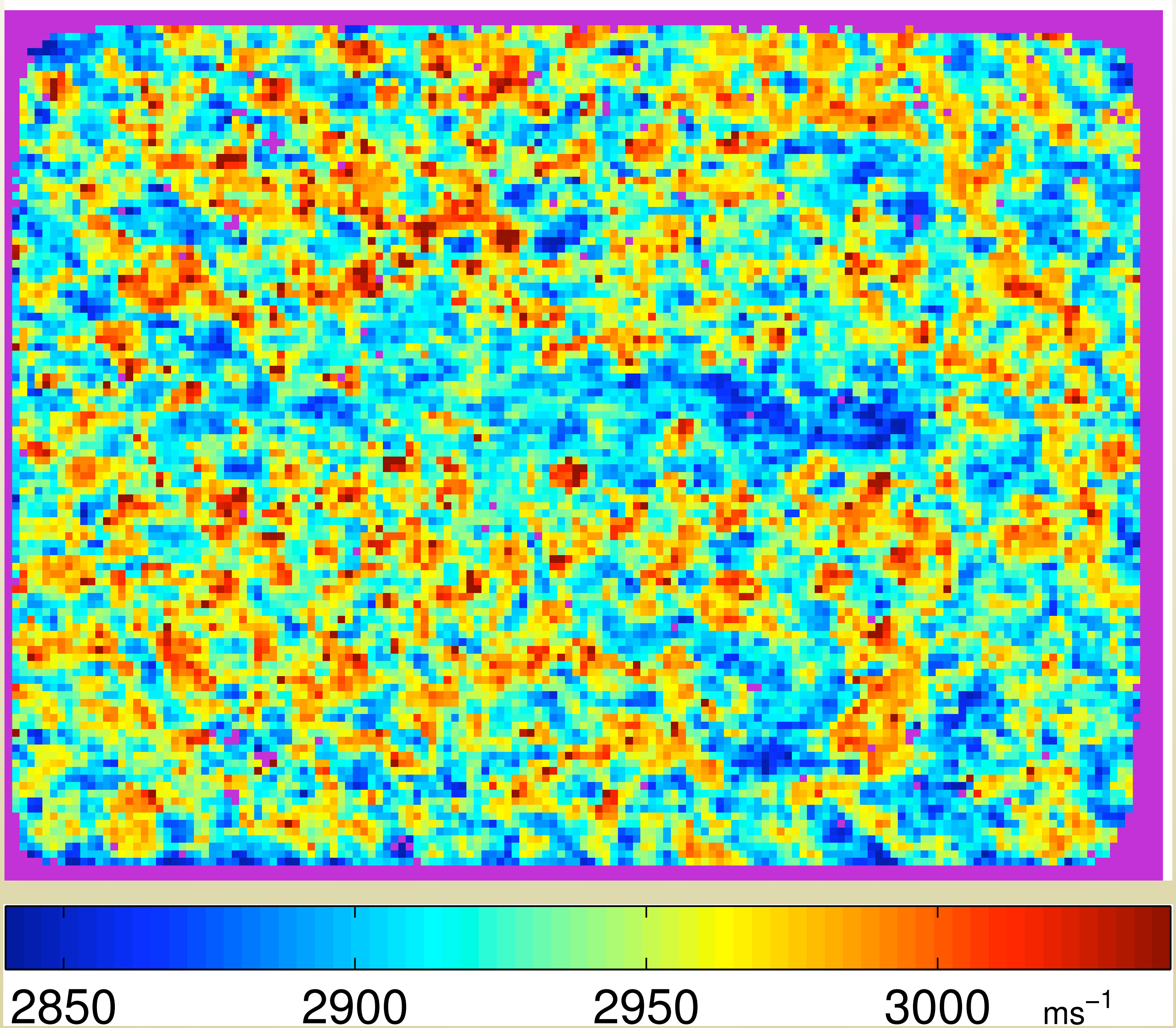
Grain clusters in titanium alloy

- 76x57mm velocity map of titanium alloy
- Colours represent SAW phase velocity in horizontal direction
- Dark blue region indicates cluster of grains of similar orientation
- Pixel size is 150μm
- Acquisition time was under 3 hours (approx 200,000 pixels)



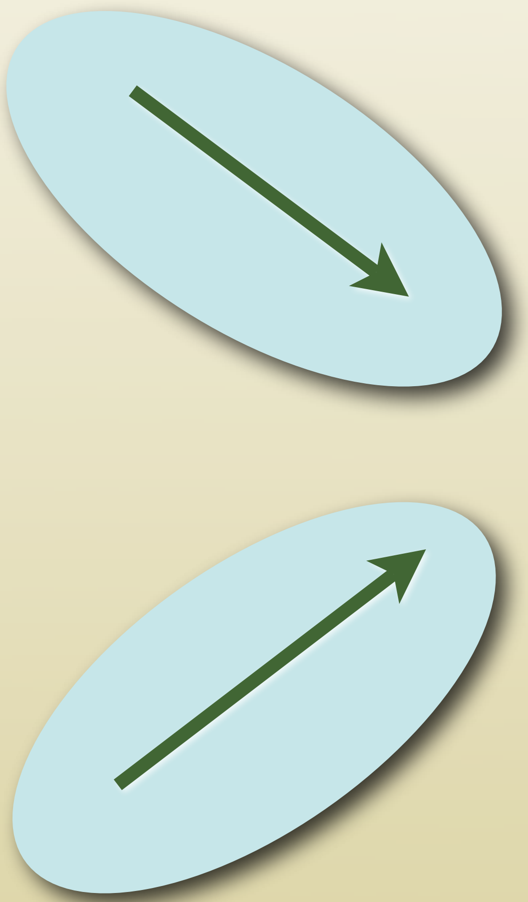
Grain clusters in titanium alloy

- 76x57mm velocity map of titanium alloy
- Colours represent SAW phase velocity in horizontal direction
- Dark blue region indicates cluster of grains of similar orientation
- Pixel size is 500µm
- Acquisition time was under 18 minutes (17,600 pixels)



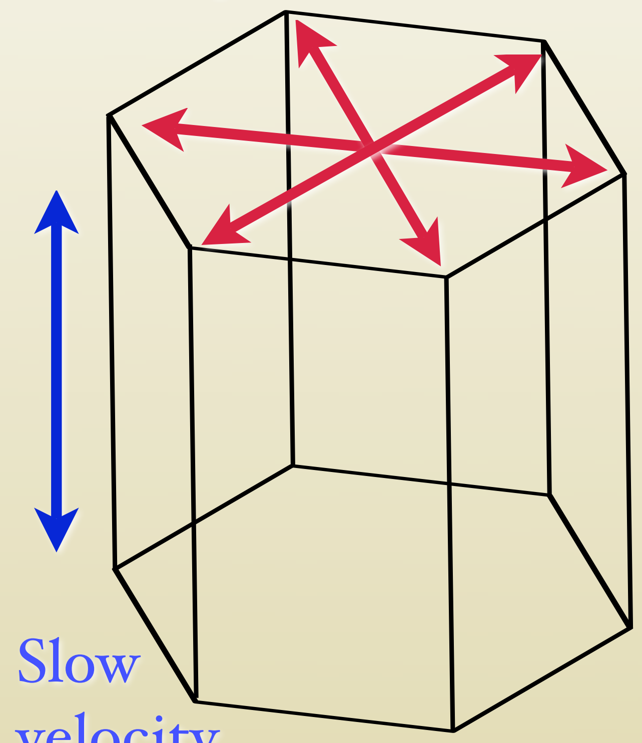
Grain orientation from velocity measurement in two directions

- We are measuring the SAW velocity in a roughly "left to right" direction
- **But** grains are 3D structures. If the arrows on the two grains here represent the fastest velocity direction, then if we just measure the SAW velocity in one direction (left to right) then the instrument will show the component of the velocity in that direction only.
- So, we need to propagate SAWs in orthogonal directions to get a fuller picture.



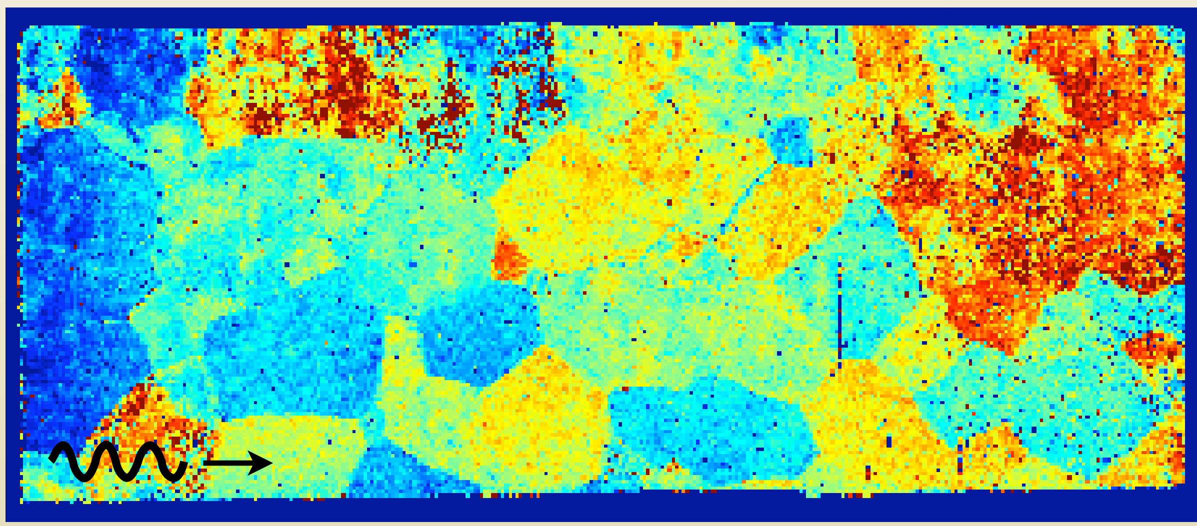
Titanium crystals

- Titanium crystals are hexagonal in structure
- Velocity varies greatly (e.g. 50%) between parallel and perpendicular directions, relative to basal plane
- By scanning at orthogonal angles, can get an idea of the angle of the basal plane

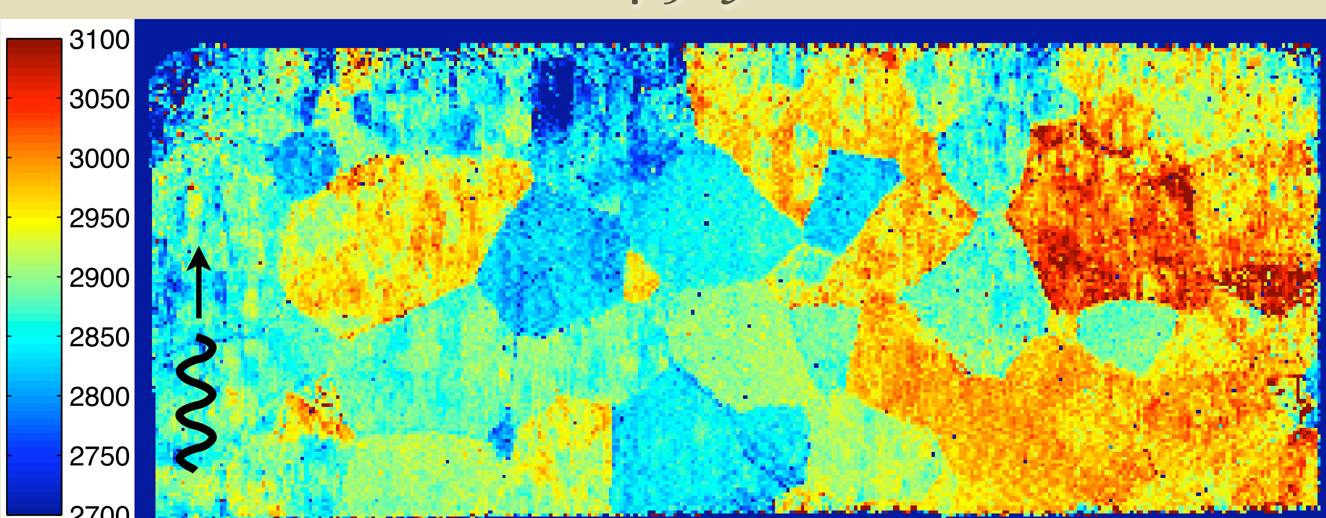


Ti-6246

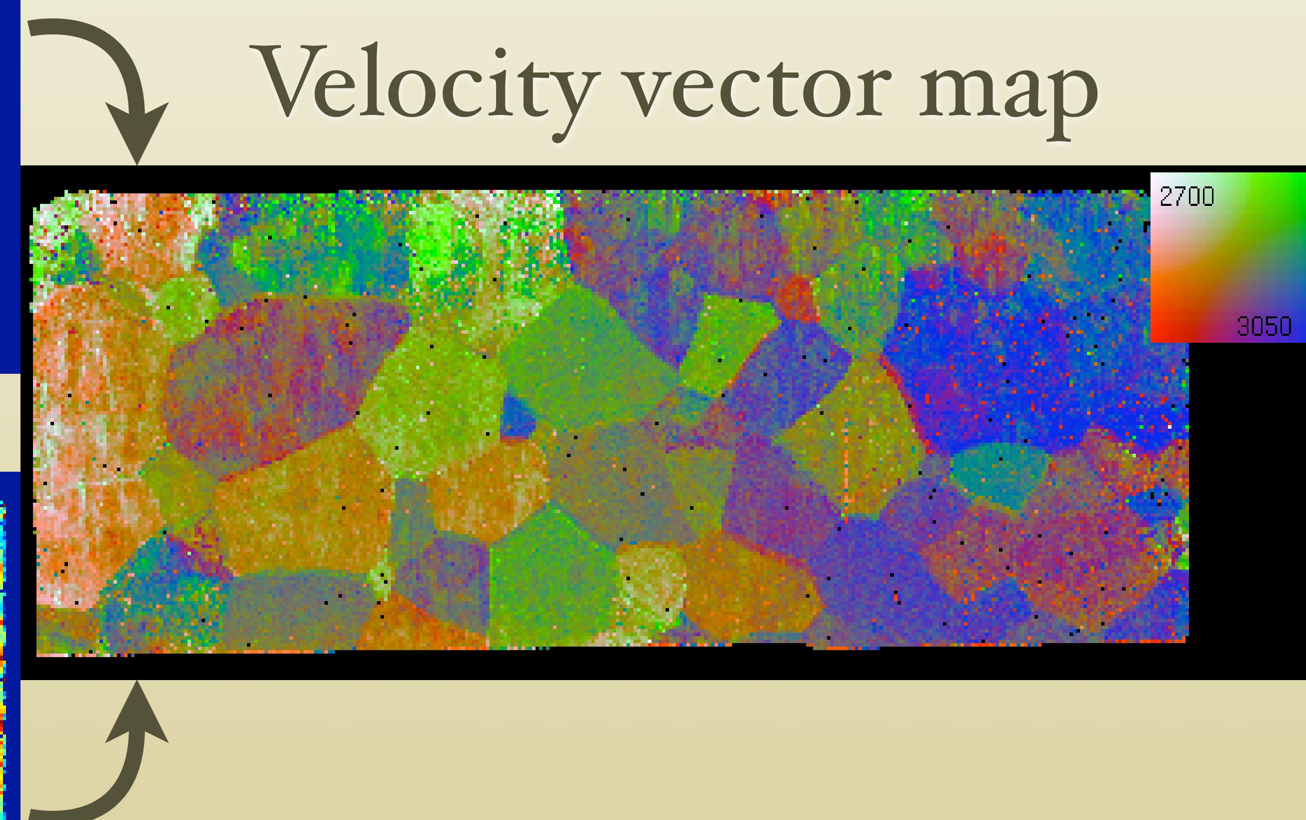
SAW velocity maps



84.5x36mm

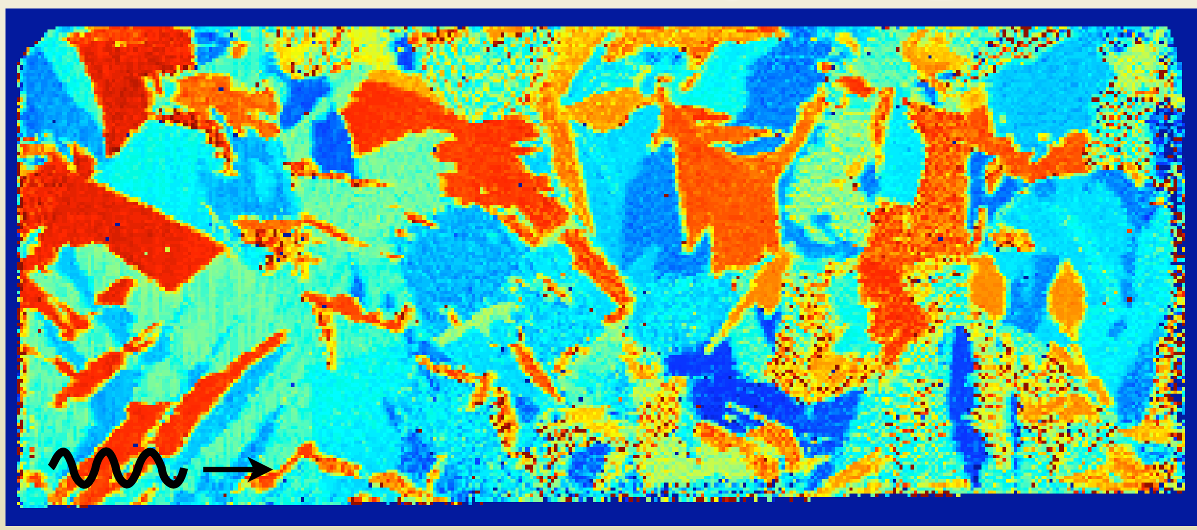


Velocity vector map

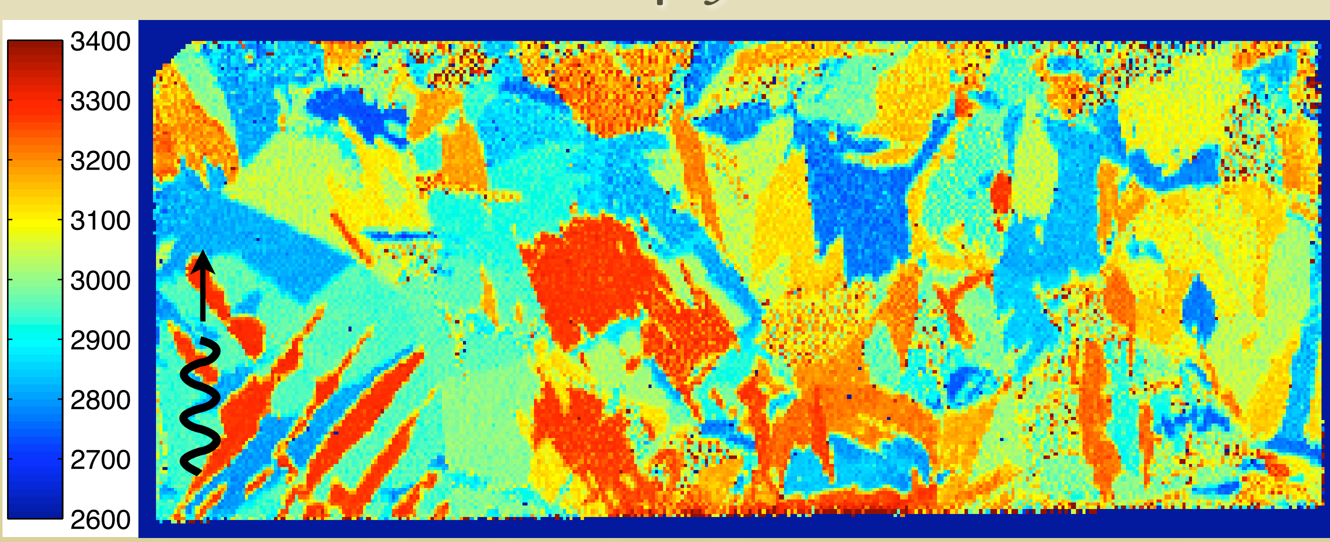


Ti-685

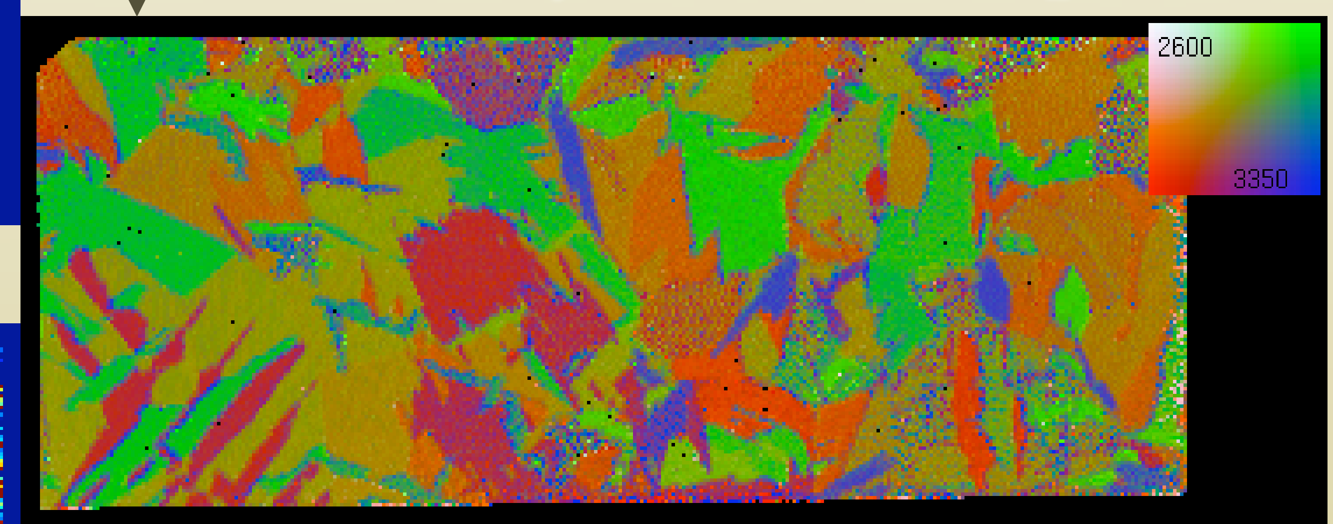
SAW velocity maps



84x36mm



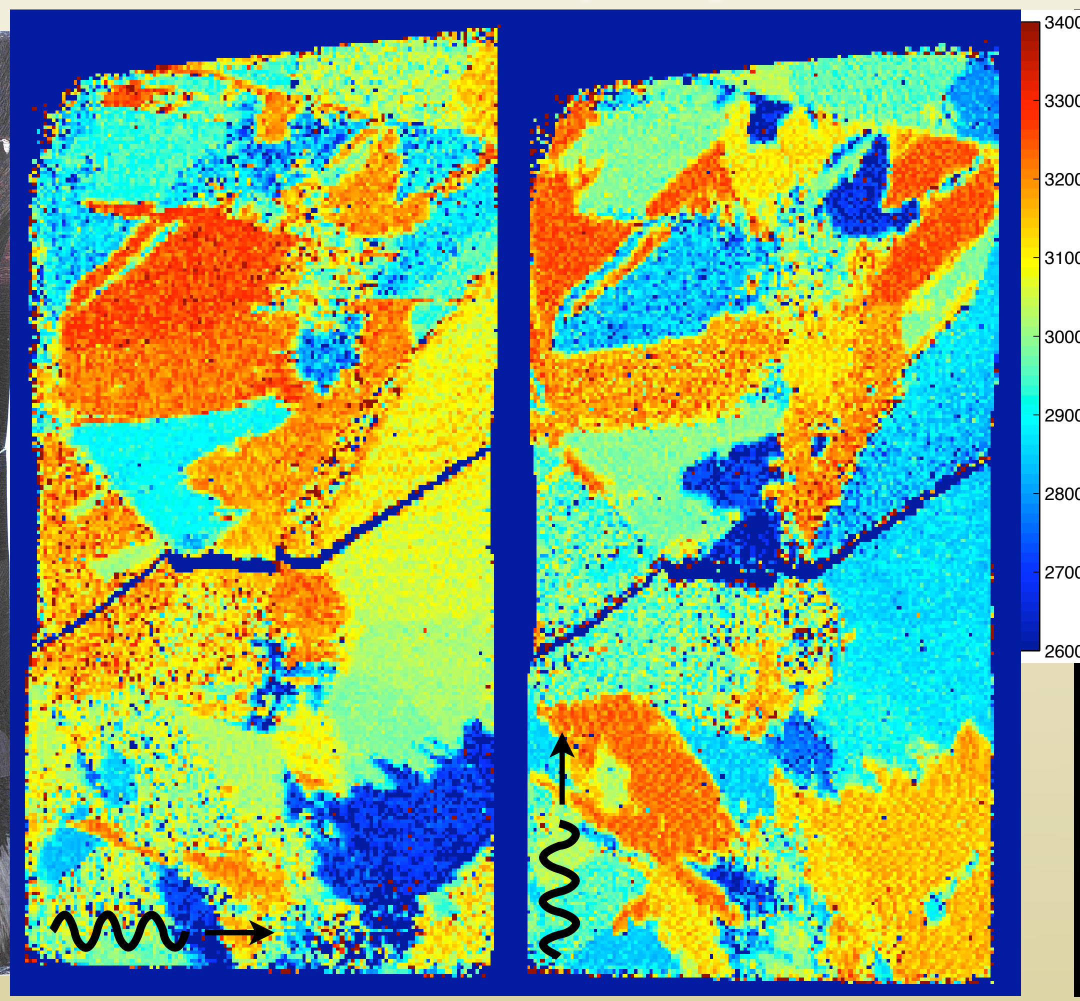
Velocity vector map



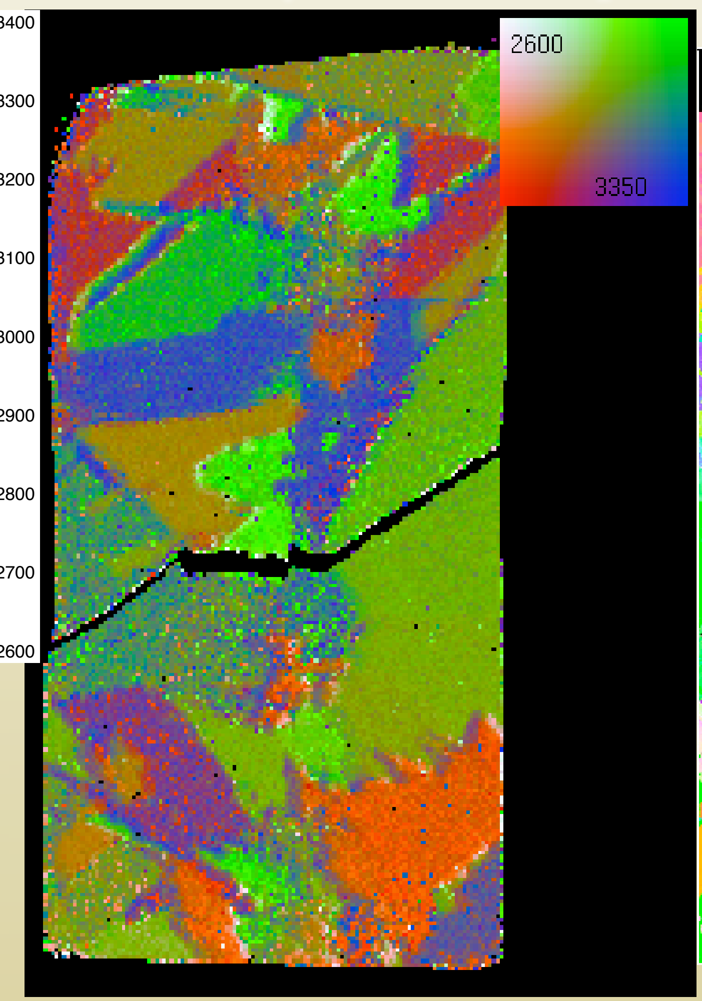
“Dwell fatigue” sample - Ti-685

Optical

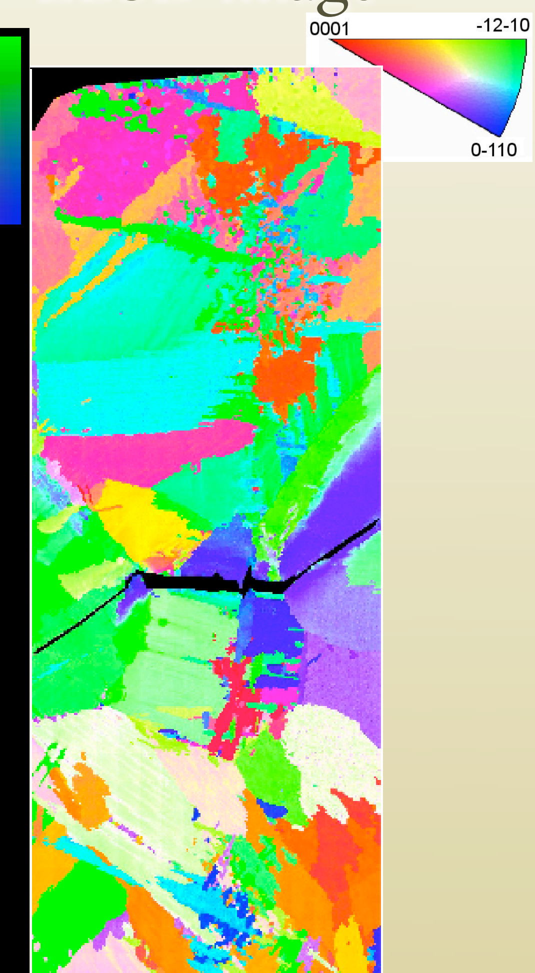
SAW velocity maps



Velocity vector map



EBSD image



27.4x52.4mm

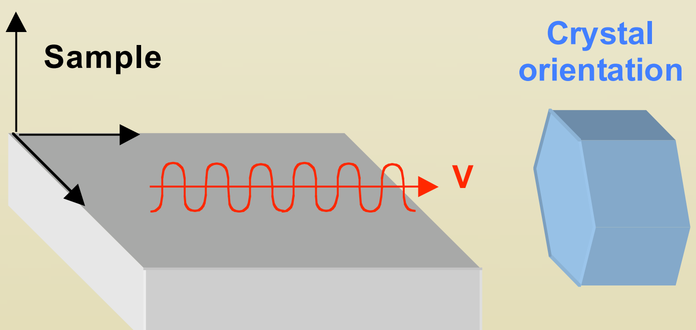
Comparison of theoretical and experimental Rayleigh velocities

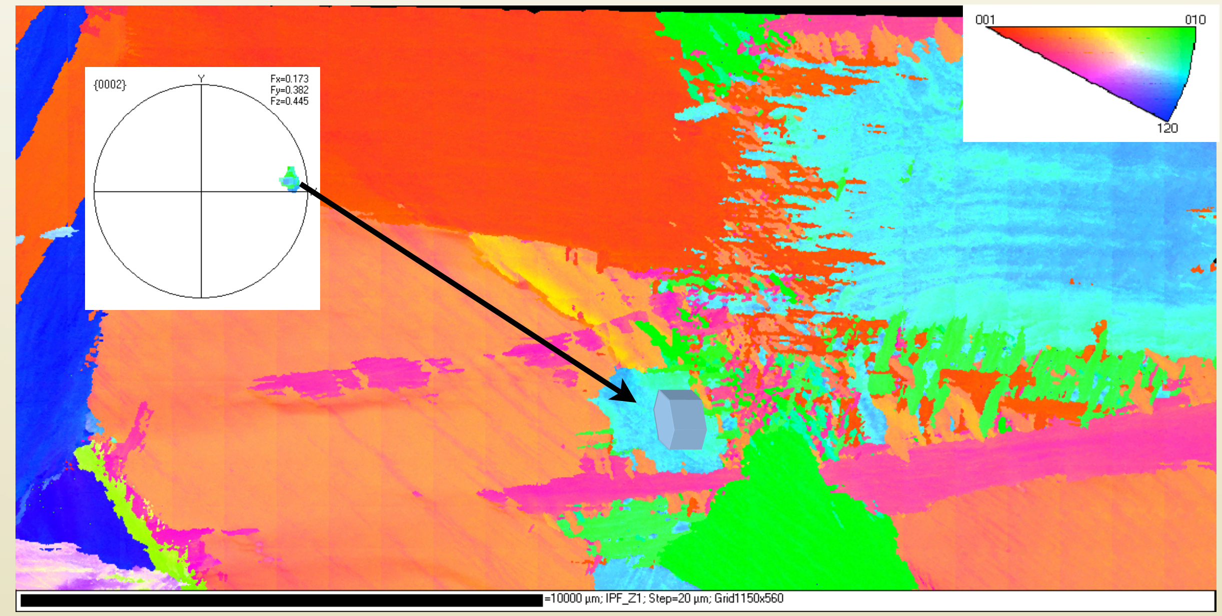
Analytical solution to wave equation for certain crystal orientations:

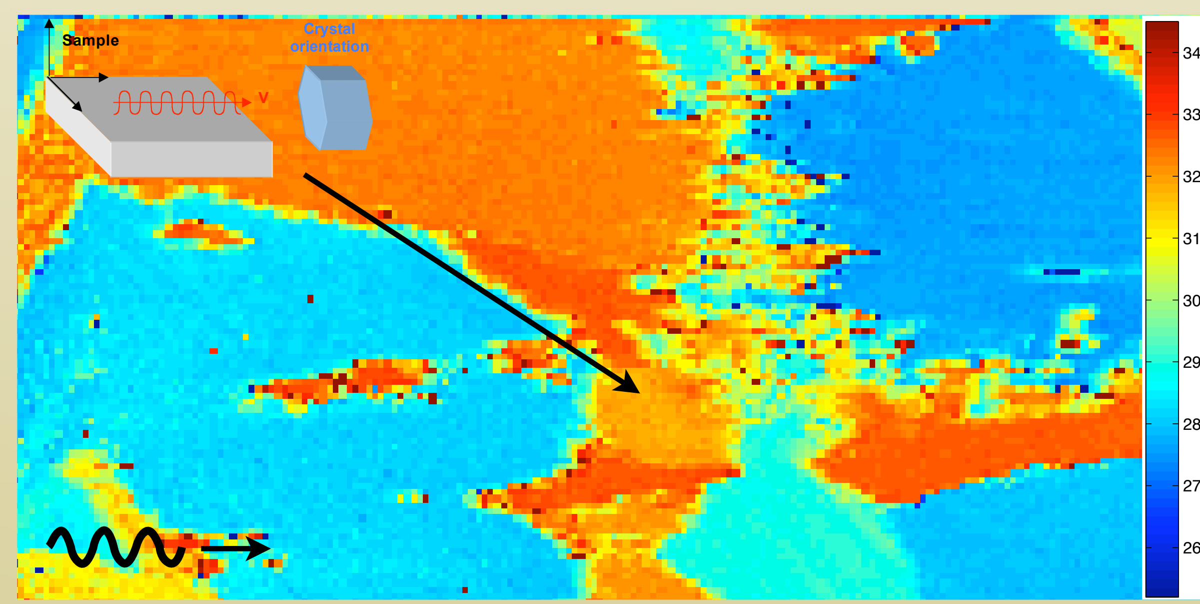
D. Royer and E. Dieulesaint, J. Acoust. Soc. Am. **76**, 1438 (1984)

$$c_{22}c_{66}\zeta^2(c_{11} - \zeta) = (c_{66} - \zeta)\left[c_{22}(c_{11} - \zeta) - c_{12}^2\right]^2$$

$$0 < \zeta_R = \varrho V_R^2 < \zeta_m = \min[c_{66}, c]$$







Theory:
V_R = 3020ms^{-1}

Experiment:
V_R = 3168ms^{-1} ±14ms^{-1}

Sample: Ti-685, 25x12.5mm

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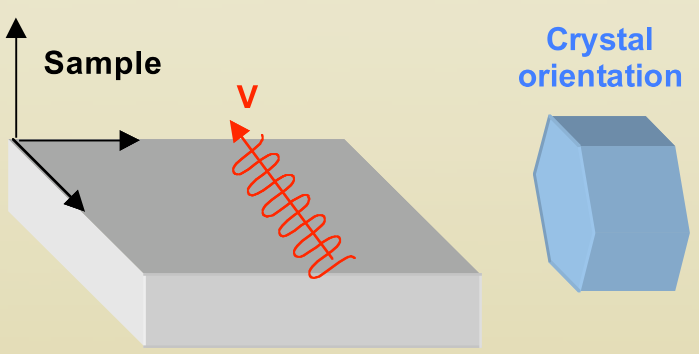

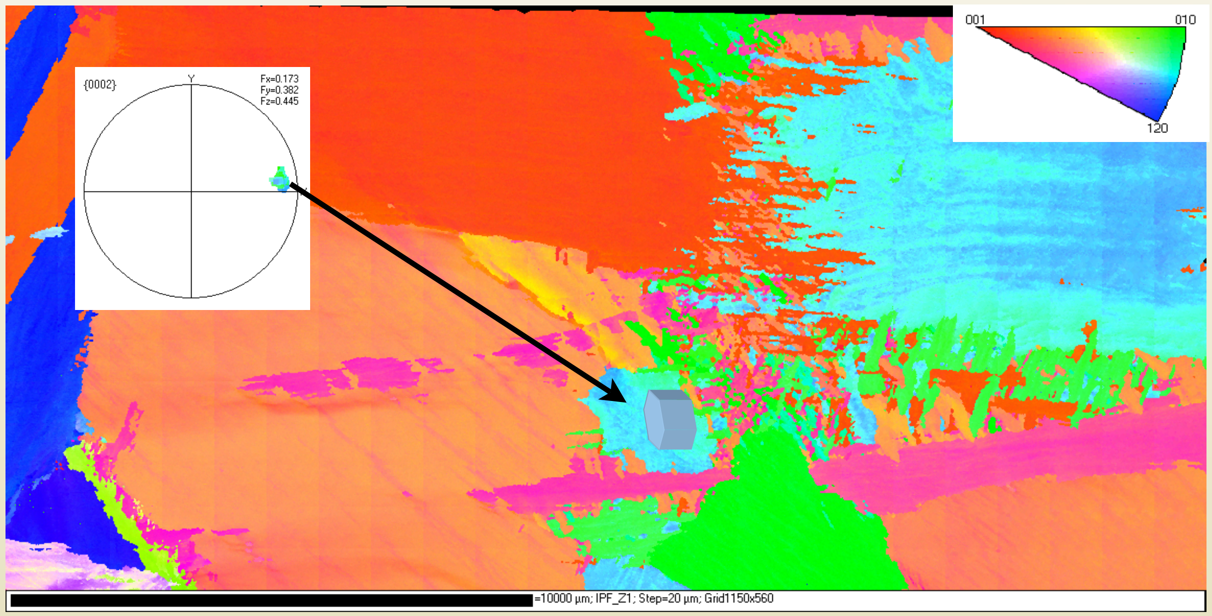

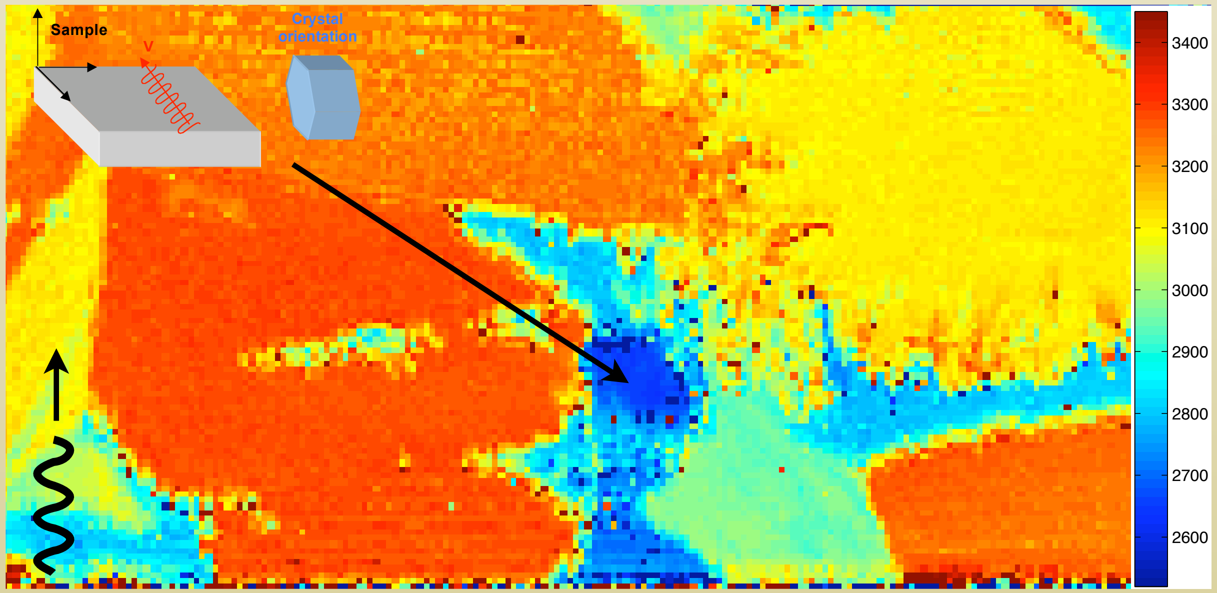

Theory:
V_R = 2618ms^{-1}

Experiment:
V_R = 2667ms^{-1} ±9ms^{-1}

Comparison of theoretical and experimental Rayleigh velocities

Analytical solution to wave equation for certain crystal orientations:

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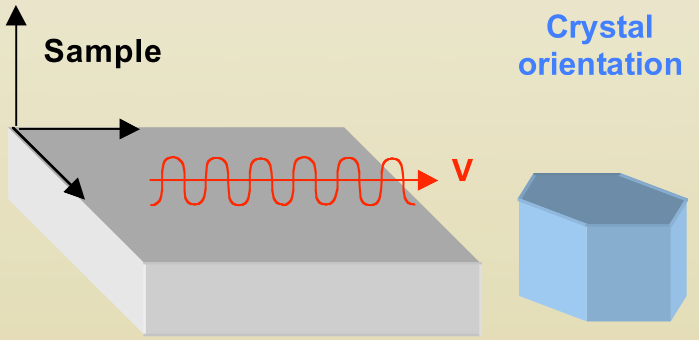

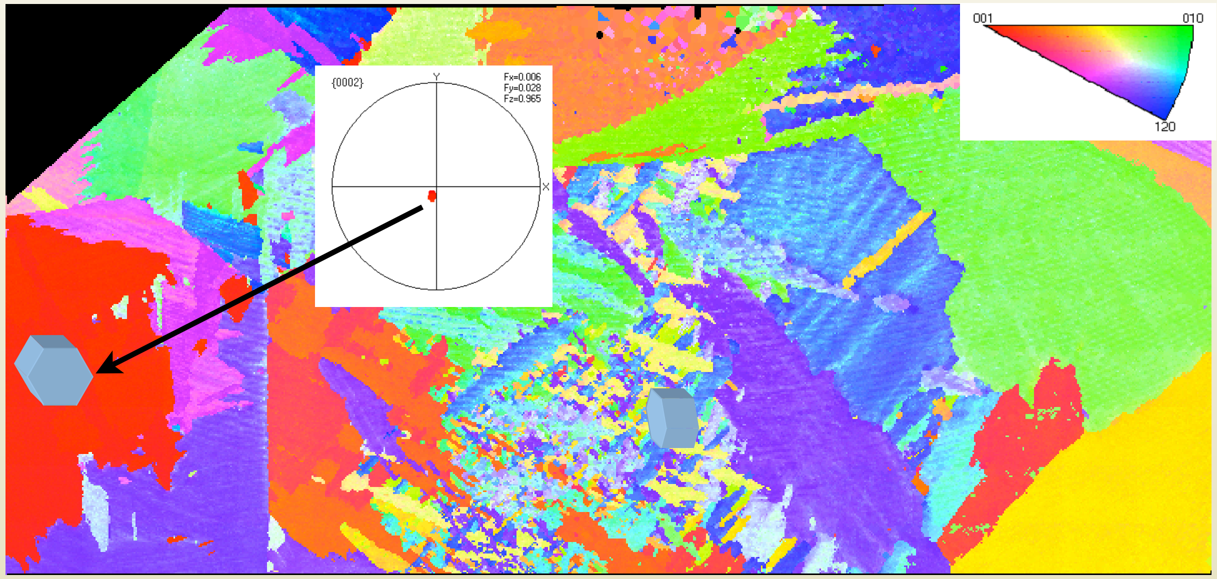

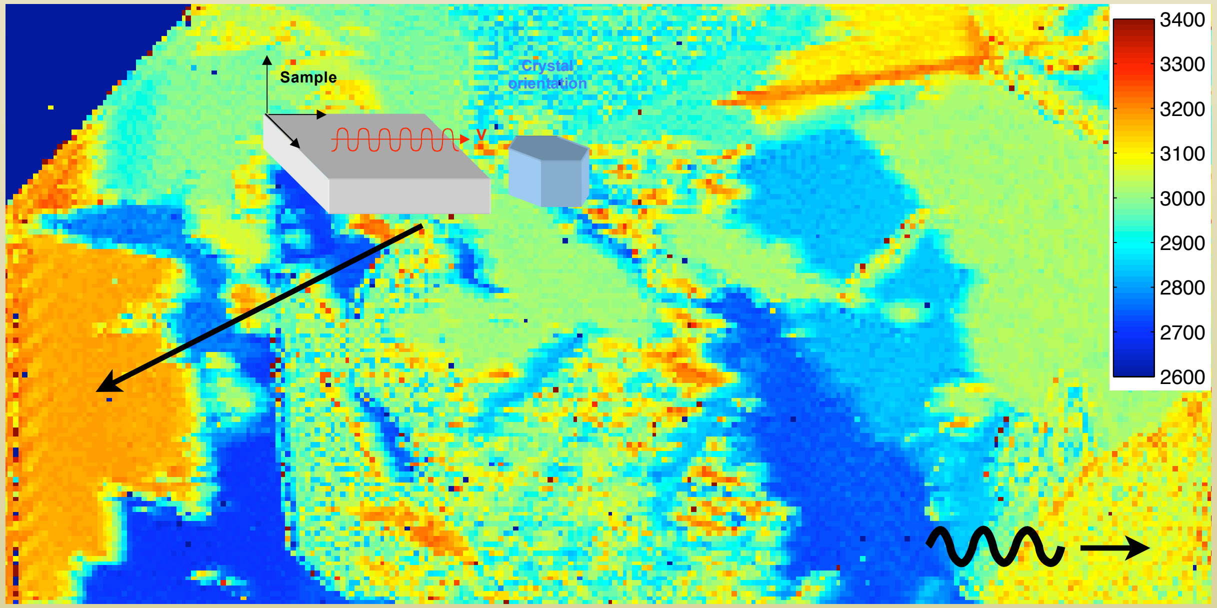

Theory:
V_R = 3012ms⁻¹

Experiment:
V_R = 3177ms⁻¹ ±10ms⁻¹

Comparison of theoretical and experimental Rayleigh velocities

Analytical solution to wave equation for certain crystal orientations:

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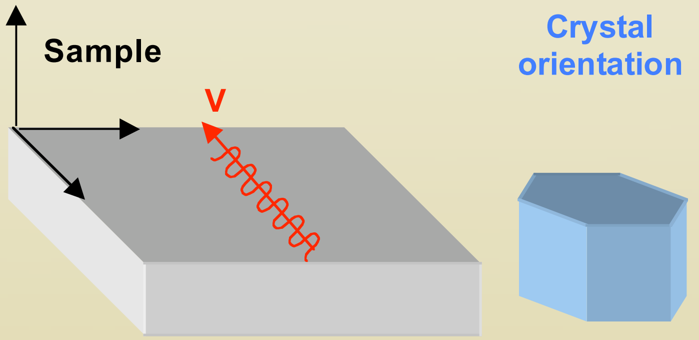
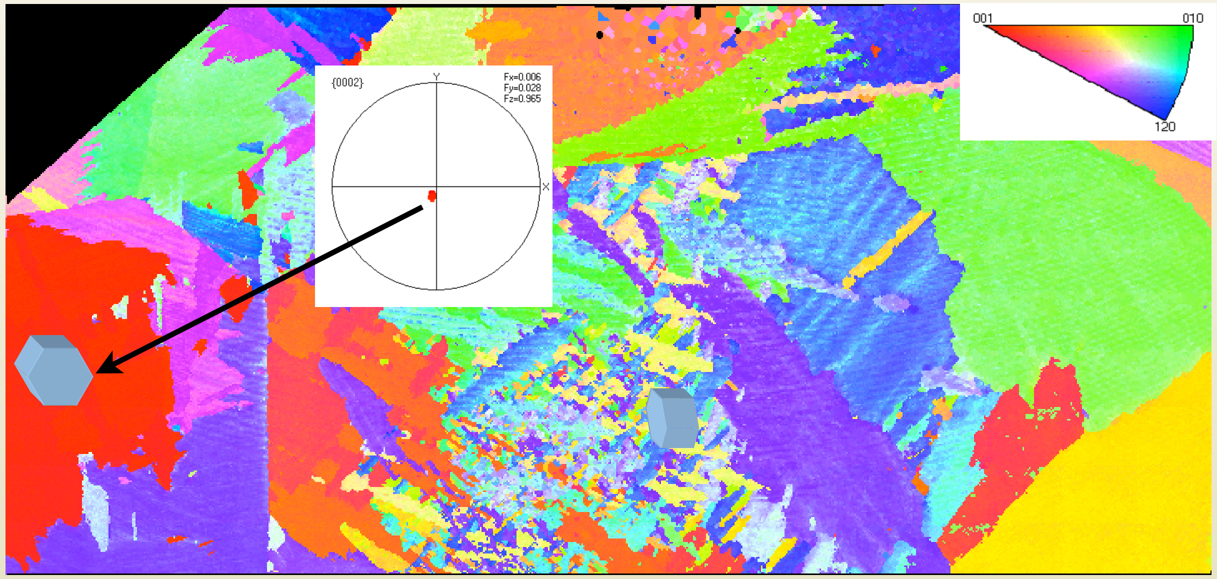
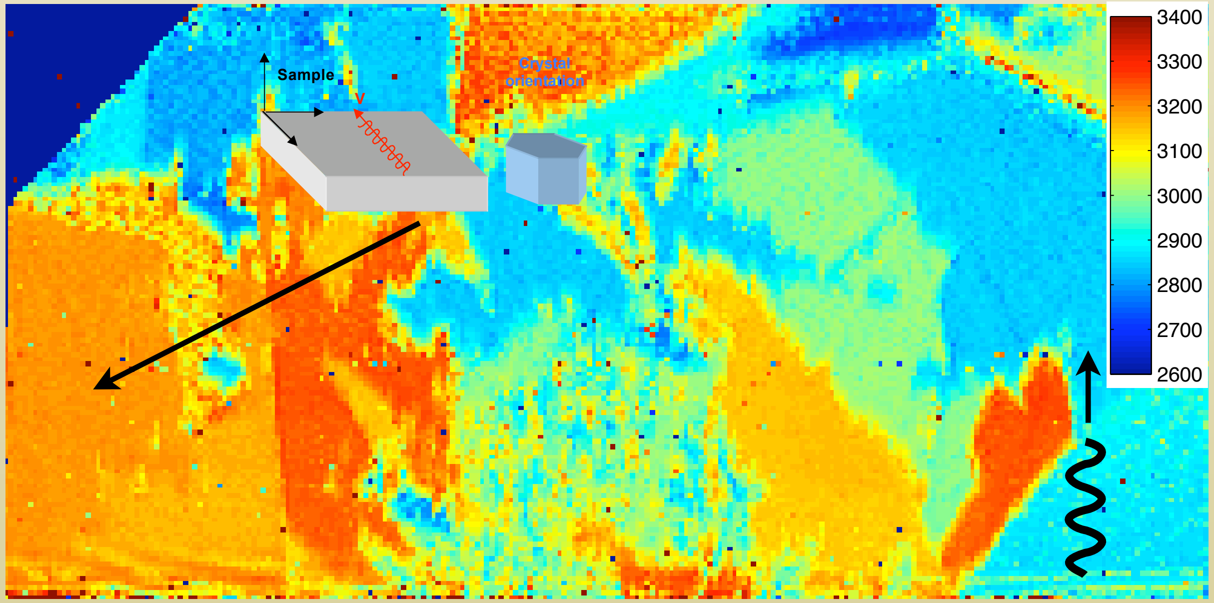


Theory:
V_R = 3012ms^{-1}

Experiment:
V_R = 3191ms^{-1} ±10ms^{-1}





SRAS: Conclusions

- SRAS is: noncontact, nondestructive, rapid, and capable of being used on pretty much any size sample
- It's capable of extracting quantitative measurements of SAW velocity in multiple directions, and some degree of spatially resolved crystal orientation information
- More work needed on tying up SAW velocity with orientation, solving the inverse problem

Thanks for your attention

I would gratefully like to acknowledge, for all the EBSD results: Lionel Germain, Liz Sackett and Martin Bache of the Materials Research Centre, University of Wales Swansea.

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