UNIVERSITY OF Southampton

Assessment of the deformation of low density polymeric auxetic foams by X-ray tomography and digital volume correlation

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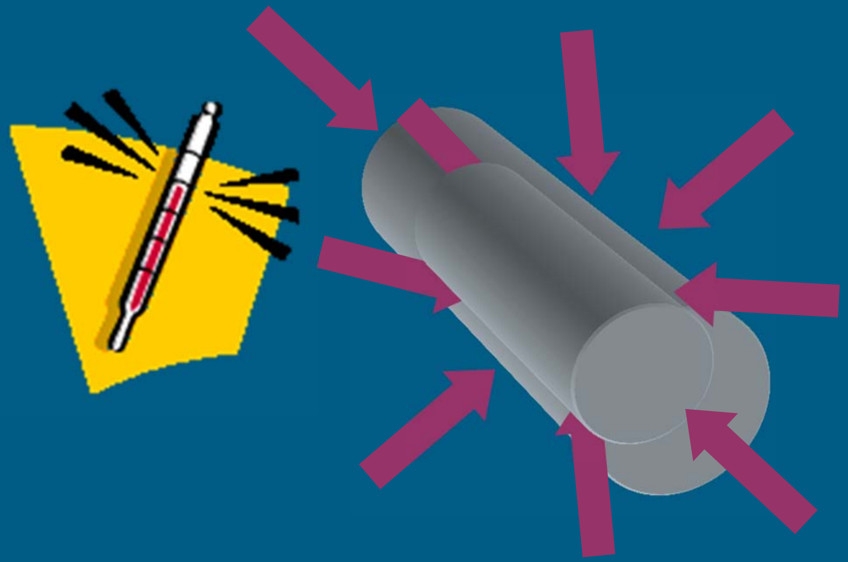
Objectives

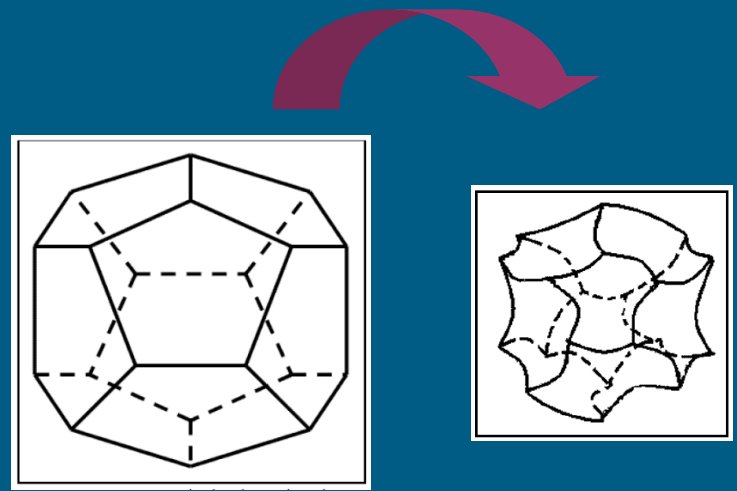
- Evaluate the preformance of Digital Volume Correlation (DVC)
  - Computed Micro X-Ray Tomography (μ**CT**)
  - Run noise performance study (stationary and rigid body movements)
- Investigate the deformation of auxetic (negative Poisson's ratio) and standard low density foam
  - Understand the deformation behaviour
  - Relate to microstructure

Experimental procedure (1/3)

- Material under study
  - Low density polyurethane (PU) foam
  - Standard foam: 45 pores/inch, density = 26-32kg.m^{-3}
  - Conversion into auxetic foam



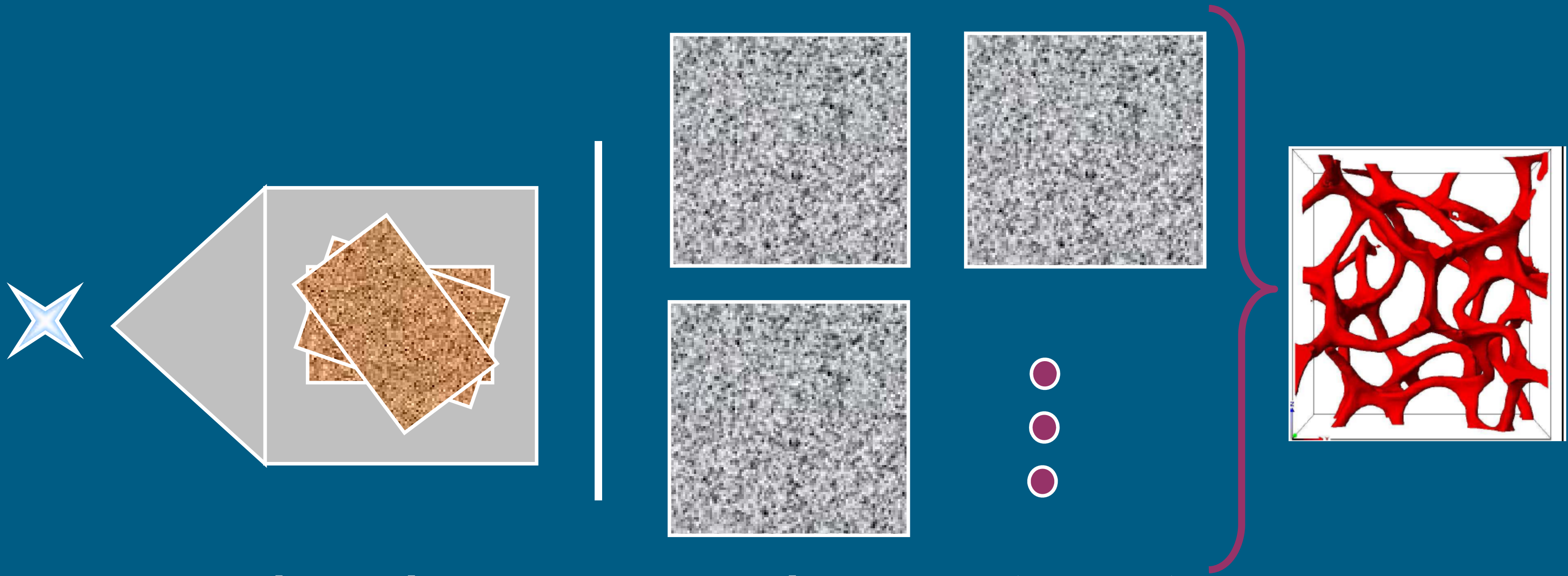
Freezes the microstructure to a folded network



Linear compression ratio: 0.67

Experimental procedure (2/3)

- X-ray computed tomography



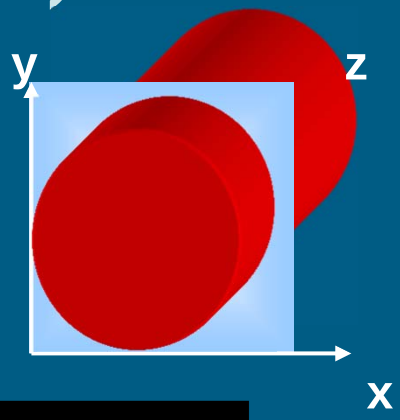
- Digital Volume Correlation (DVC)
  - Extension to volume of digital image correlation
  - LaVision DVC software

Experimental procedure (3/3)

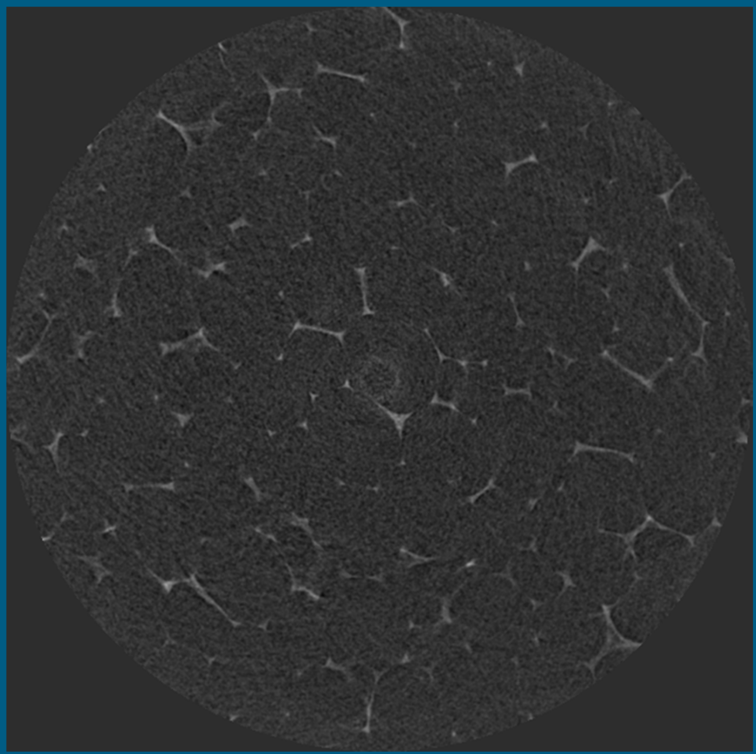
- Digital Volume Correlation (DVC)
  - Local approach (each sub-volume pattern correlated independently)
  - Multi-pass approach: large sub-volumes initially used to capture large displacements. Displacements used as initial input for smaller sub-volumes, ensuring the pattern is followed and signal to noise ratio maximised.
  - Piecewise linear shape functions
  - Gaussian curve-fitting of the correlation function peak for subvoxel resolution.

Performance evaluation (1/12)

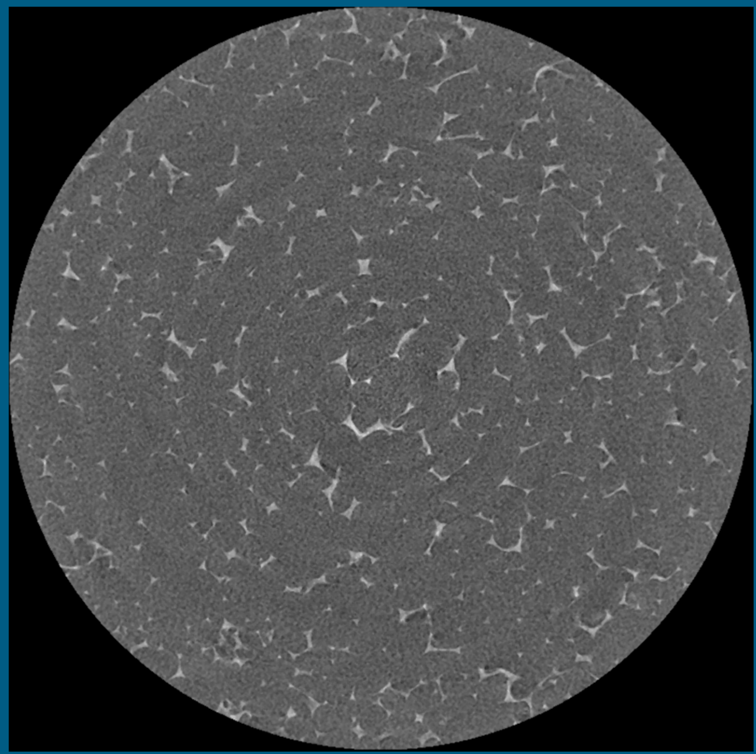
- Raw images (cylindrical specimens)



Standard

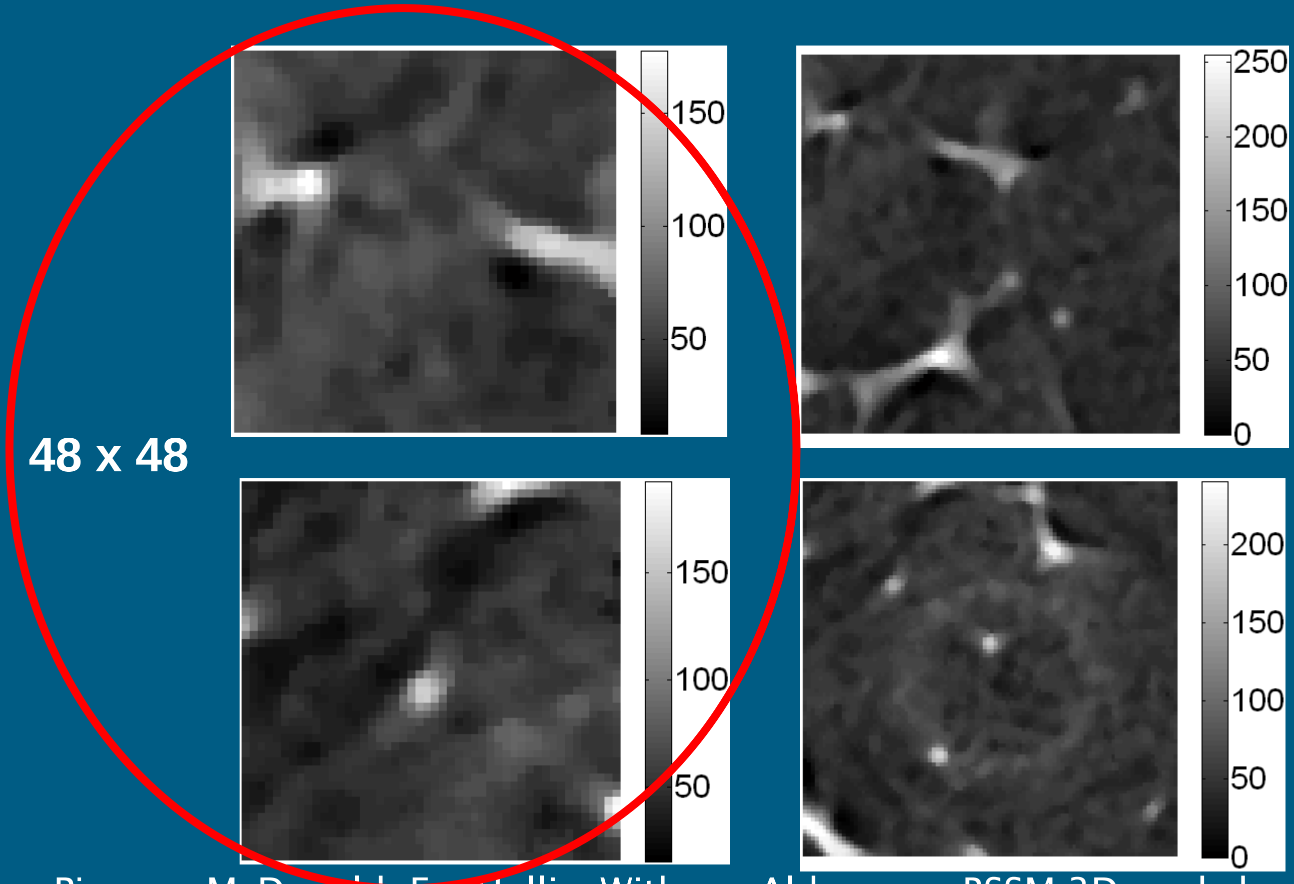


Auxetic



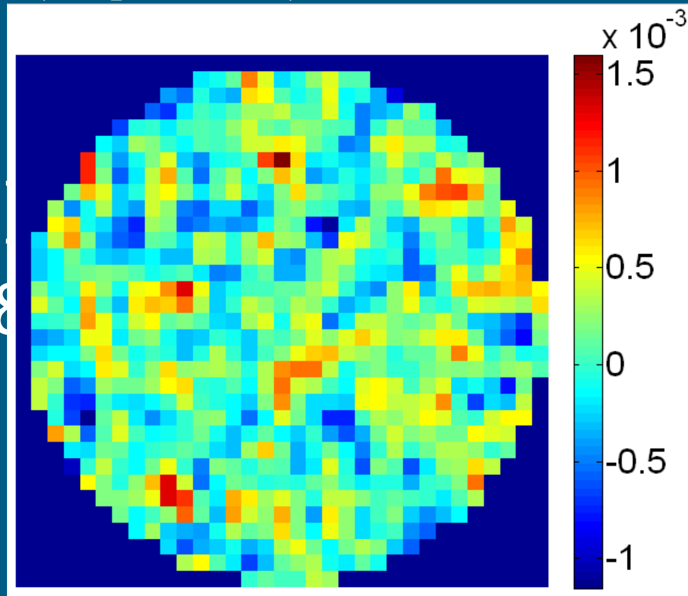
Performance – auxetic (2/12)

- Auxetic raw images: cylindrical specimen
  - Field of view 800 x 800 x 679
  - Voxel size: 15 microns

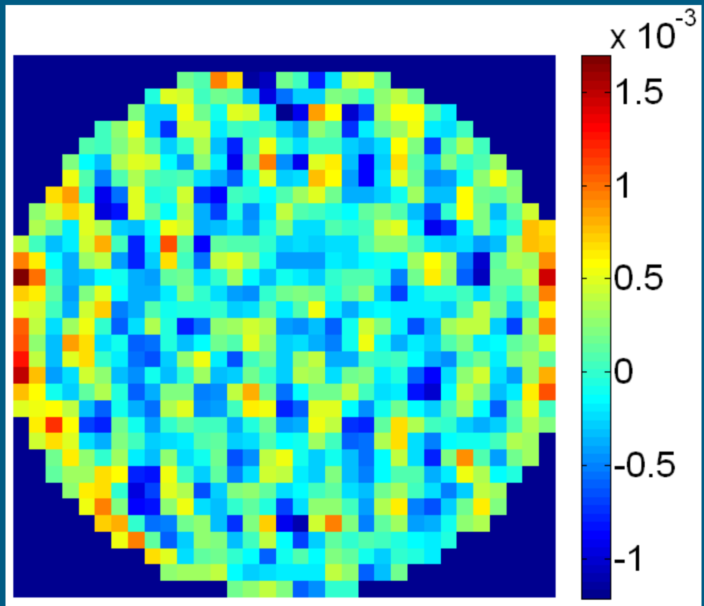


Performance – auxetic (3/12)

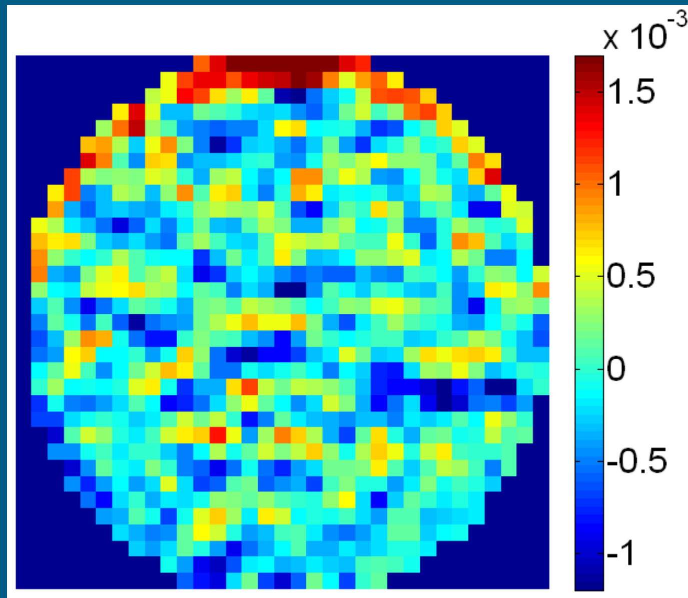
- Stationary specimen
  - 48 x 48 x 48, step 50% (24
  - Final data size: 33 x 33 x 2
  - Strains in central slice ε_{yy}
  - **No smoothing**



ε_{xx}

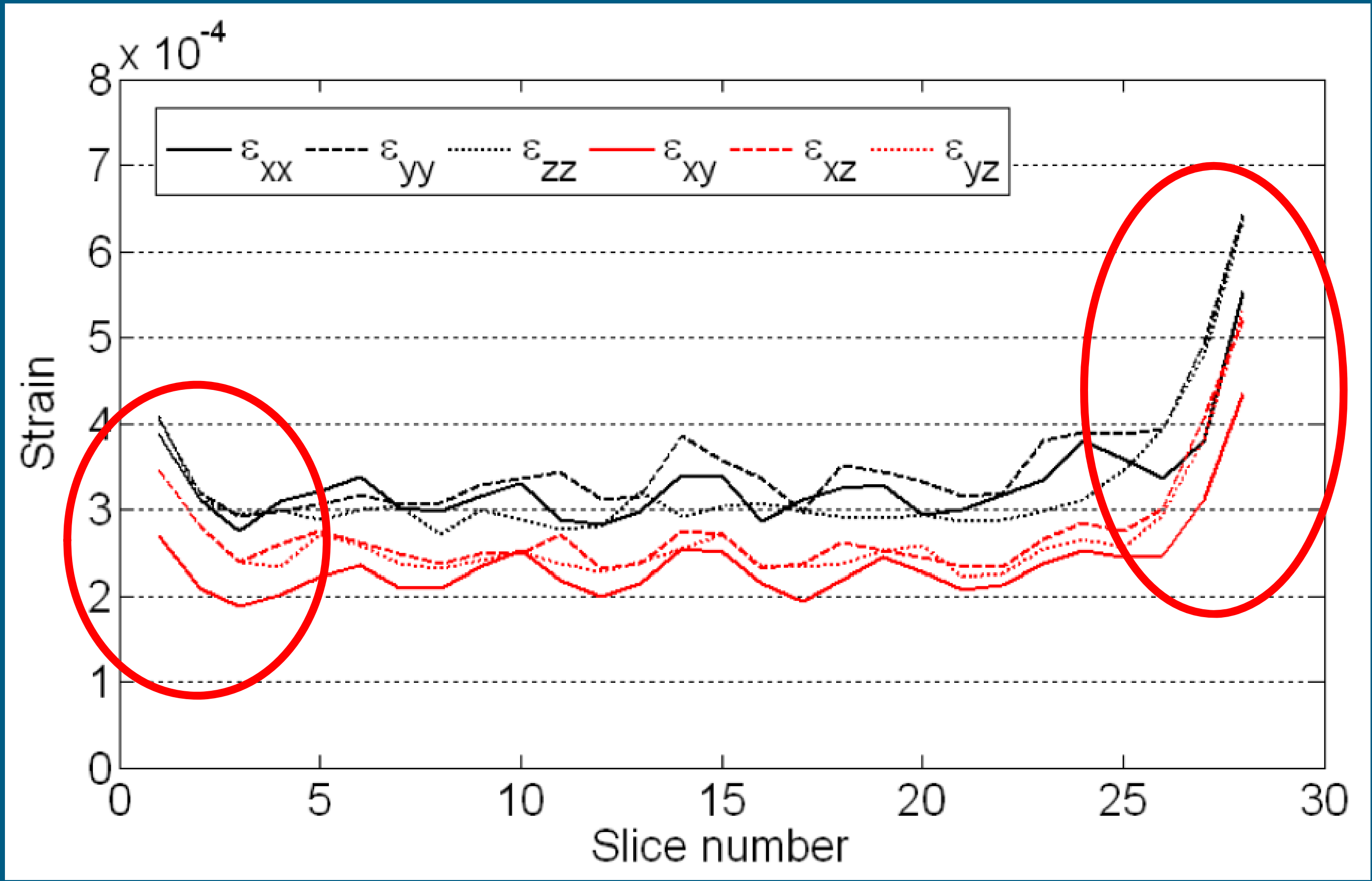


ε_{zz}



Performance – auxetic (4/12)

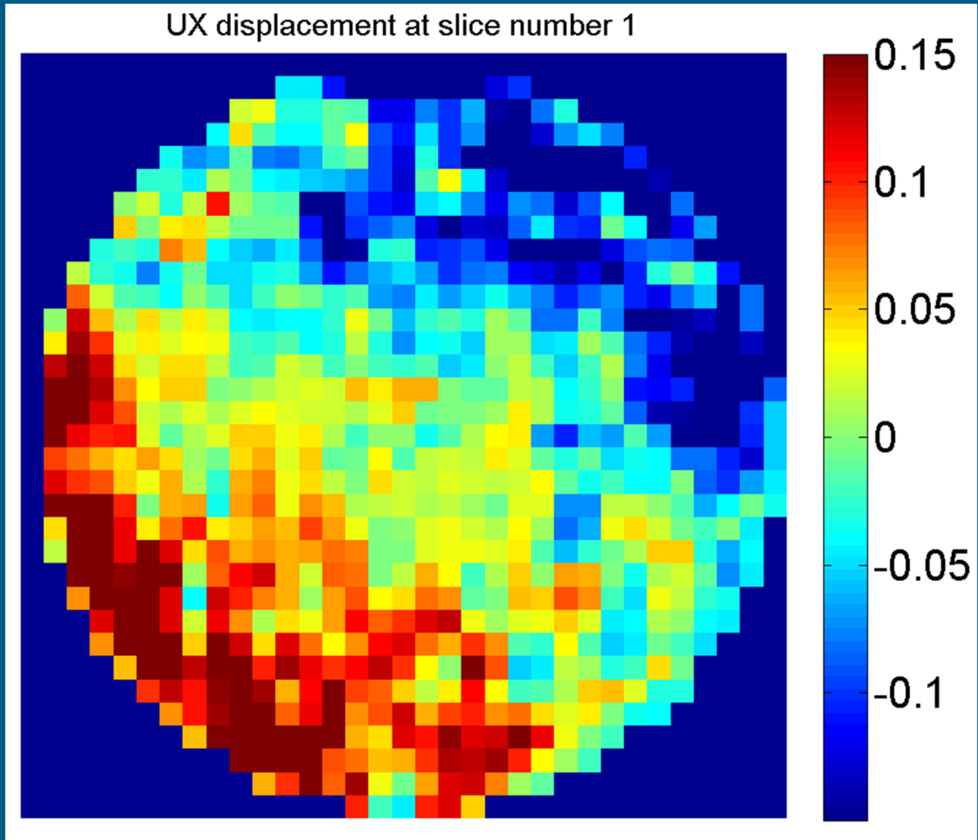
- Stationary auxetic specimen
  - Strain resolution in Z-slices



Performance – auxetic (5/12)

- Rigid body translation along Z
  - About 30 voxels

$U_X - \overline{U_X}$ represented to in order to use the same scale



Displacements in voxels

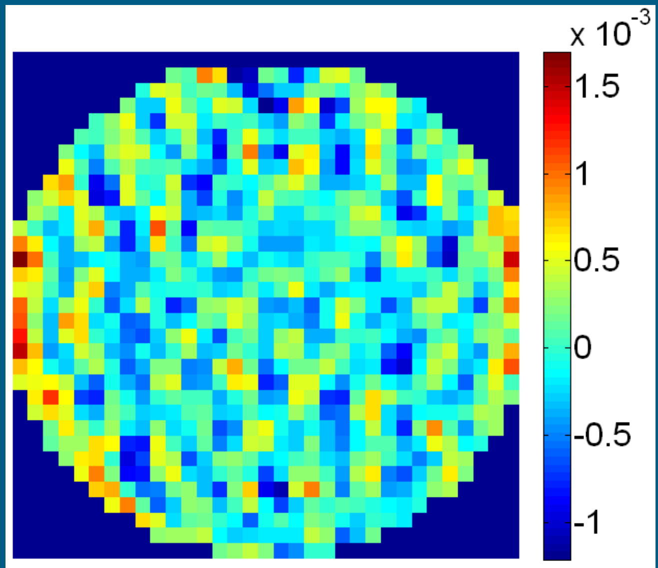
Translation not perfectly in Z-direction

Inaccurate data for couple of first and last slices

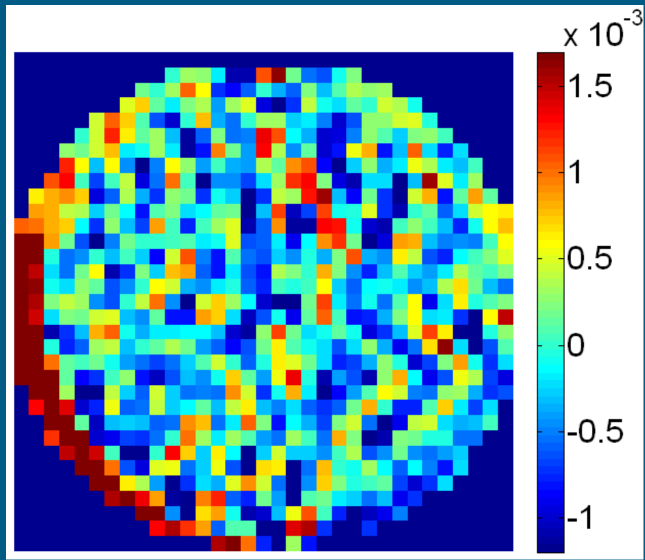
Performance – auxetic (6/12)

- Rigid body translation along Z
  - Strain components, no smoothing

ε_{xx}



Stationary

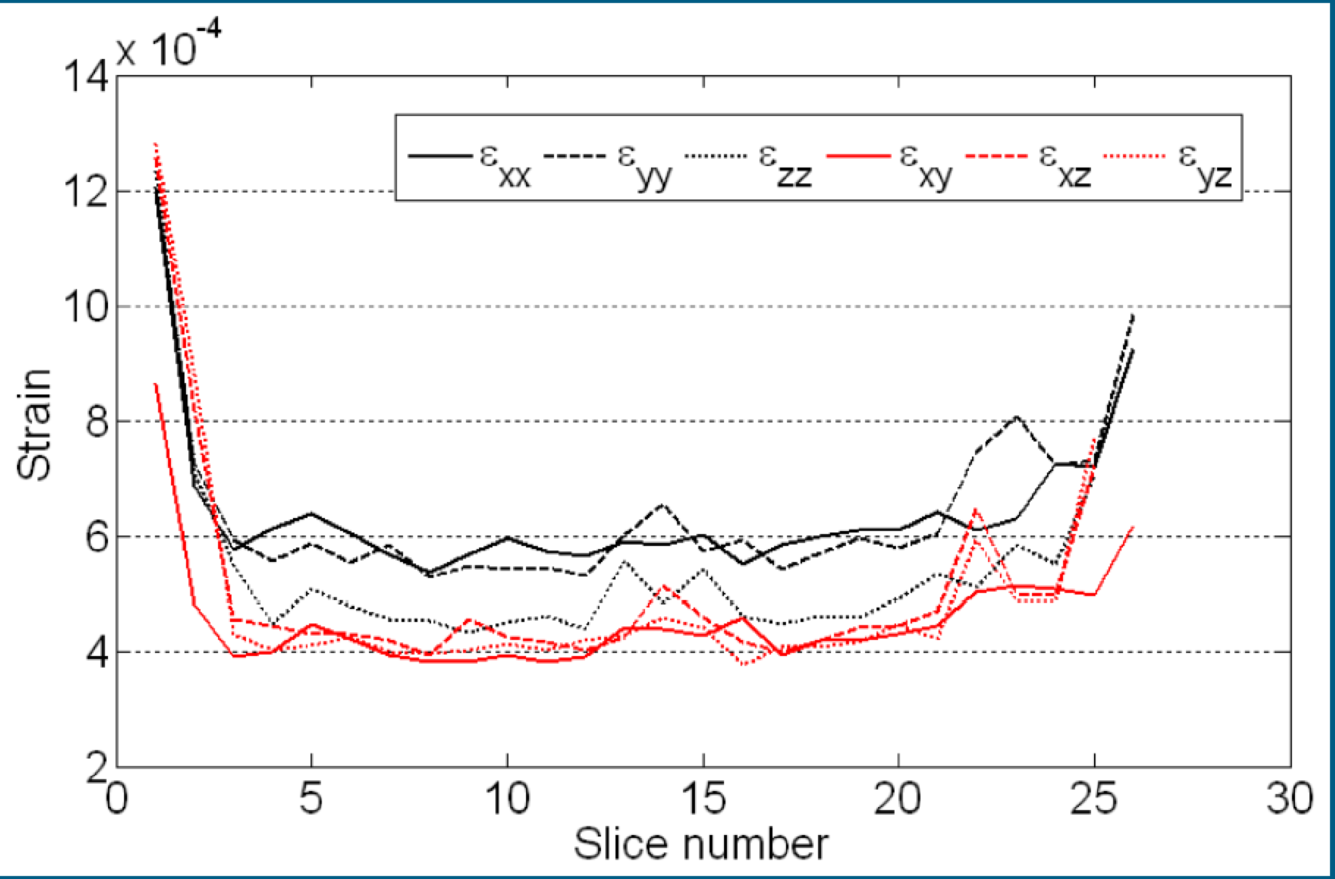


Rigid body

Limited spatial correlation (shift of 50%)

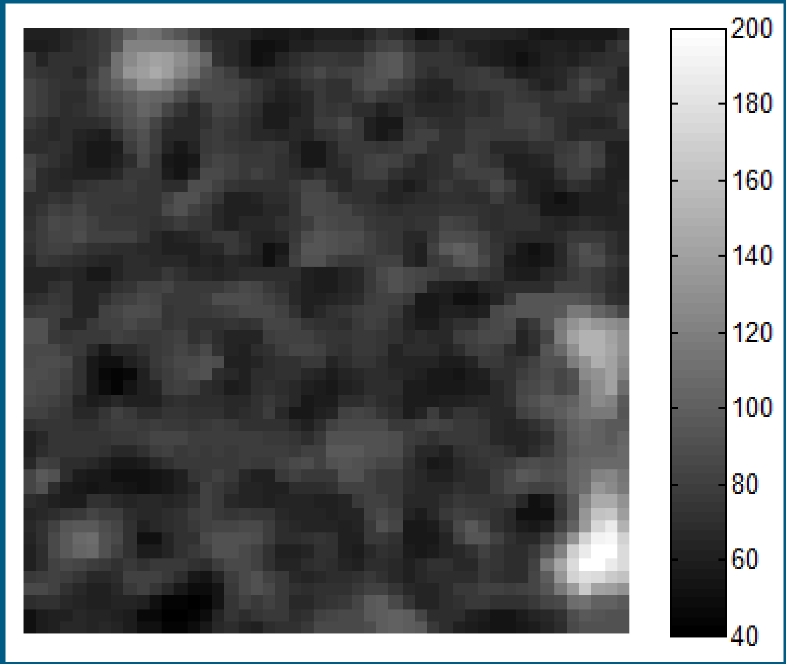
Performance – auxetic (7/12)

- Rigid body translation along Z
  - Strain resolution

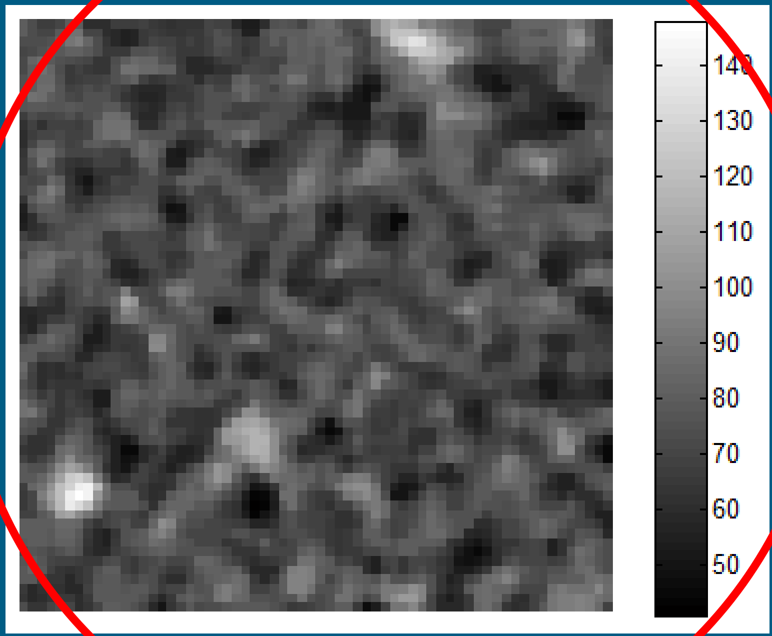


Performance – standard (8/12)

- Standard raw images: cylindrical specimen
  - Field of view 1000 x 1000 x 1000
  - Voxel size: 15 microns



48 x 48



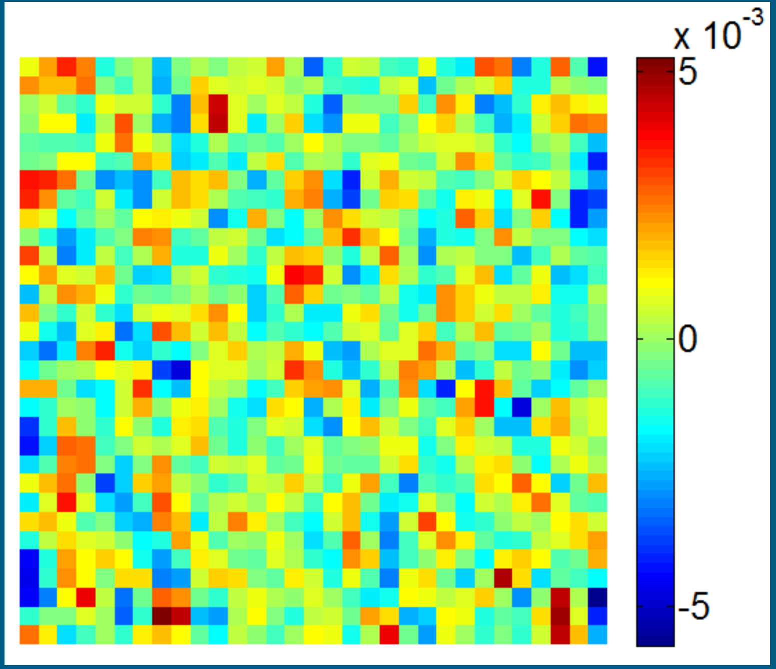
64 x 64

Follows compression ratio of 0.67

Performance – standard (9/12)

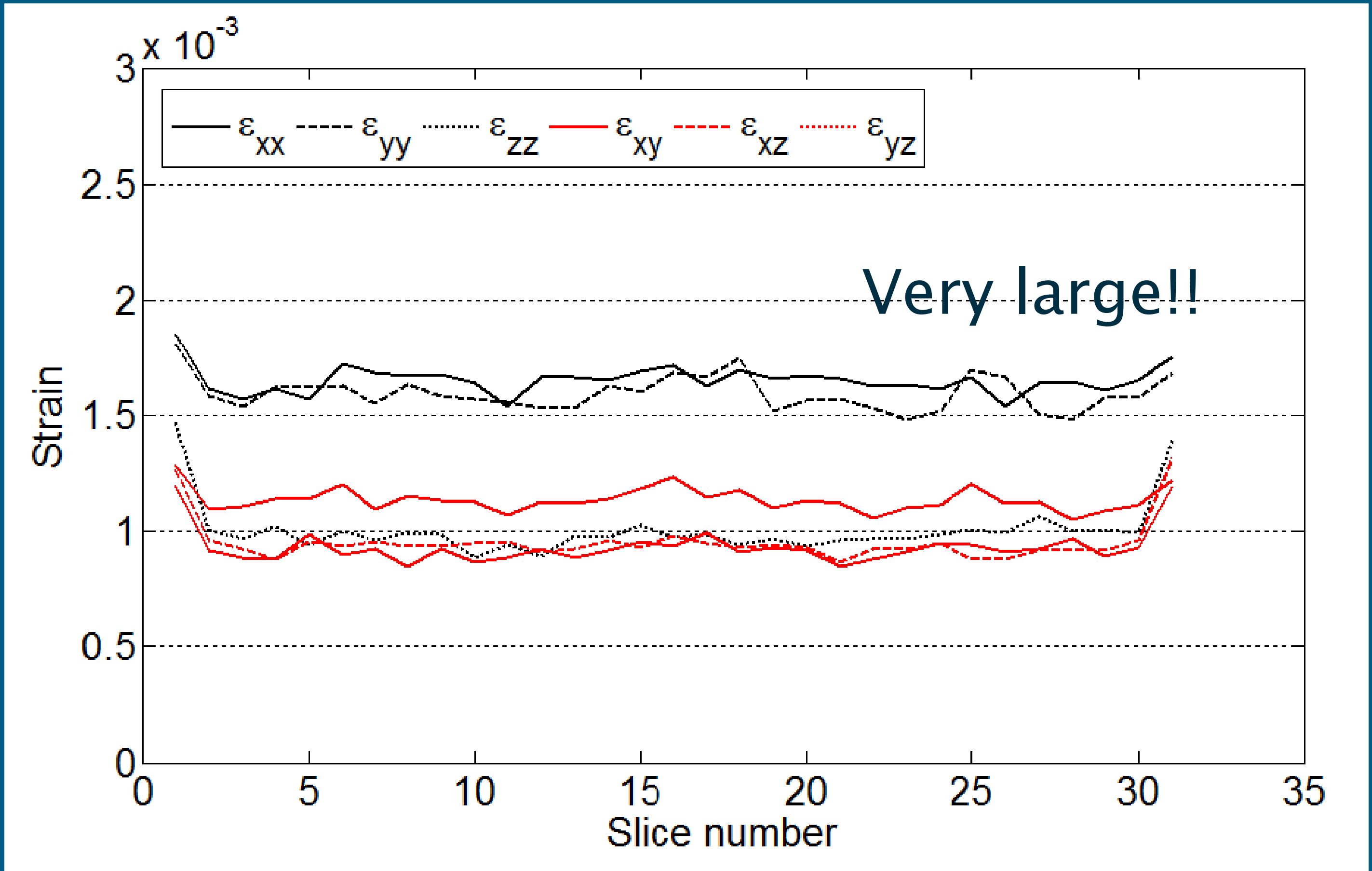
- Stationary specimen
  - 64 x 64 x 64, step 50% (32)
  - Final data size: 31 x 31 x 31
  - Strains in central slice
  - **No smoothing**

ε_{xx}



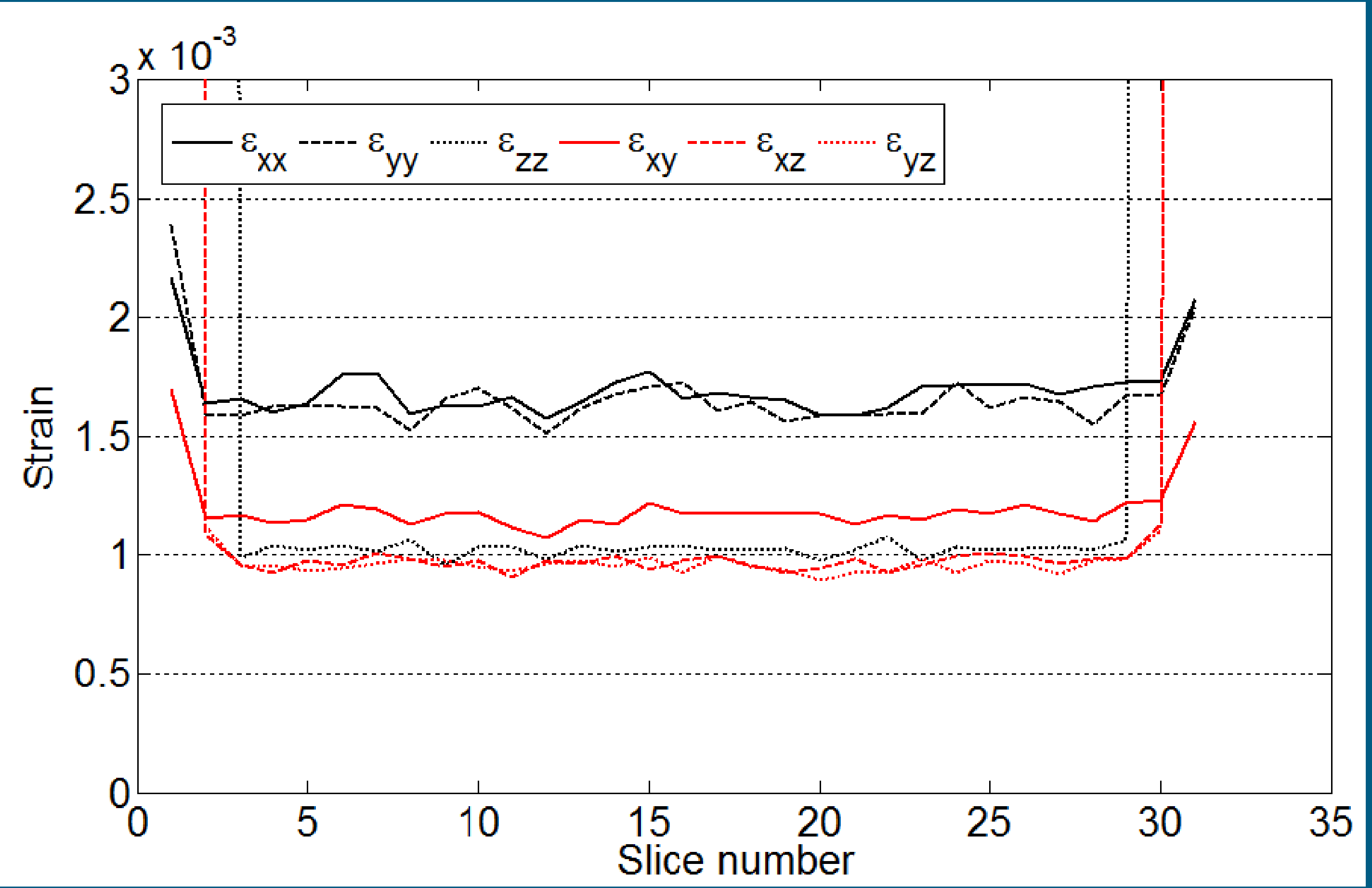
Performance – standard (10/12)

- Stationary specimen
  - Strain resolution in Z-slices



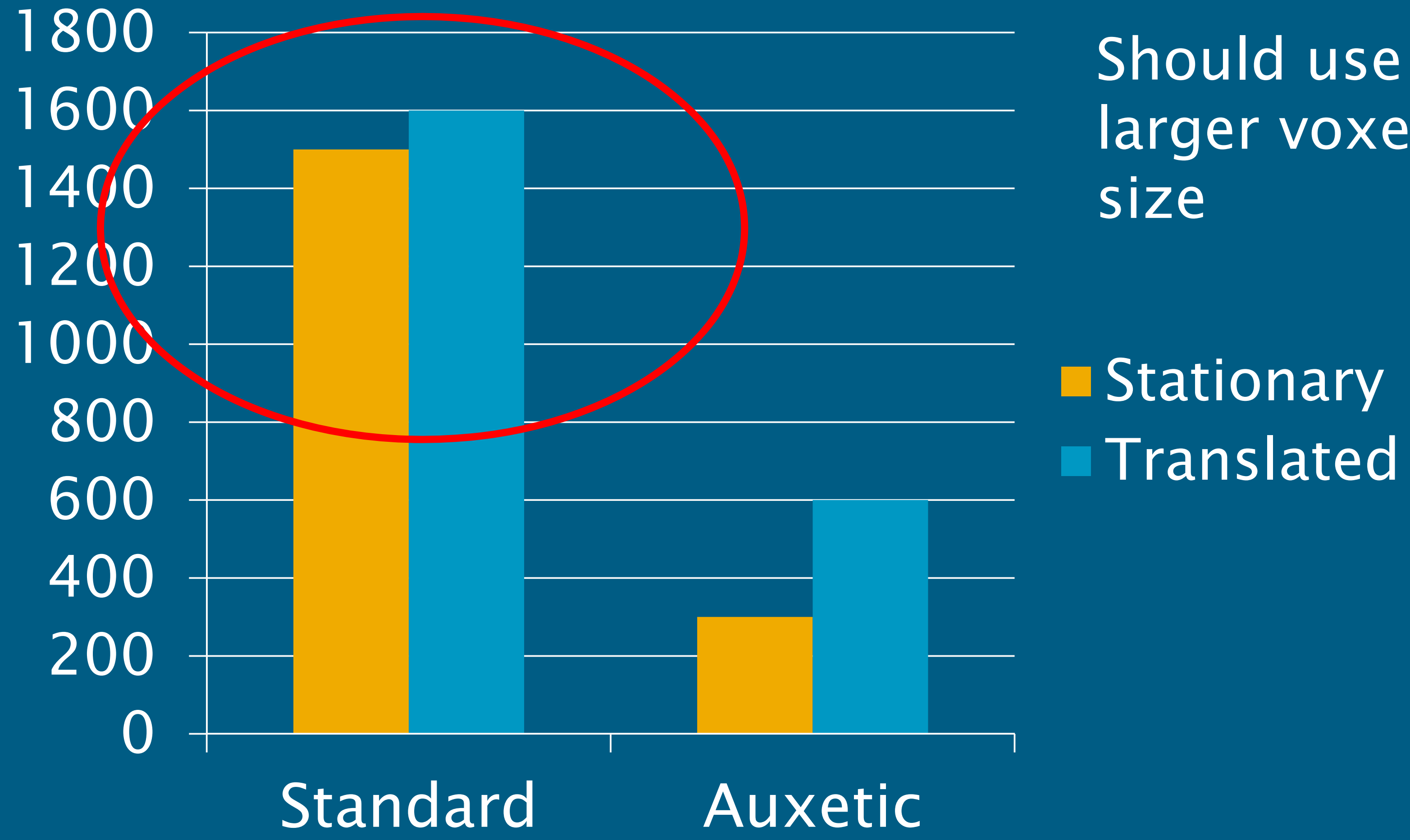
Performance – standard (11/12)

- Rigid body translation along Z
  - Strain resolution in Z-slices



Performance – standard (12/12)

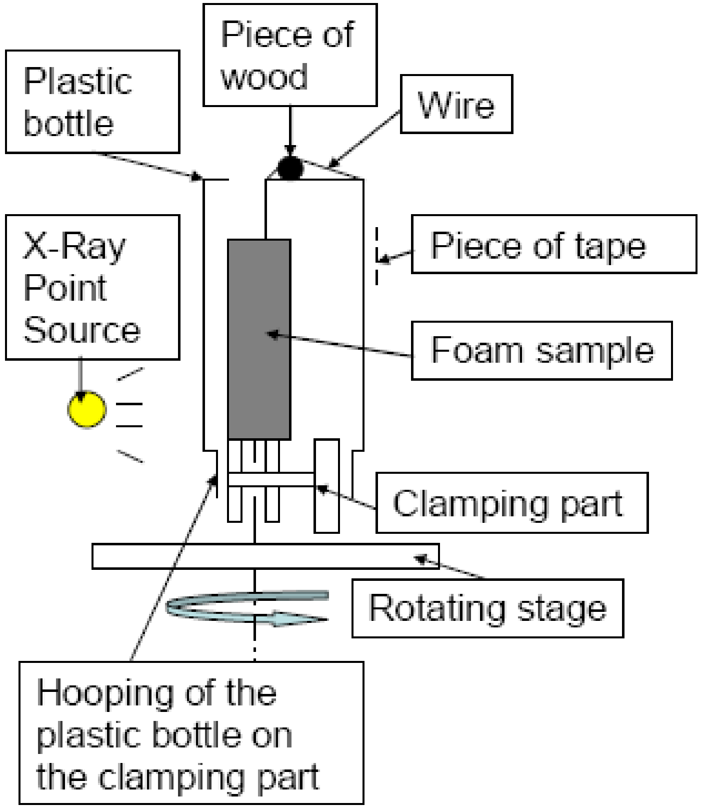
- Wrap up: strain resolution (microstrains)



Should use larger voxel size

Tensile tests (1/7)

- Load in Z-direction
  - Test fixture

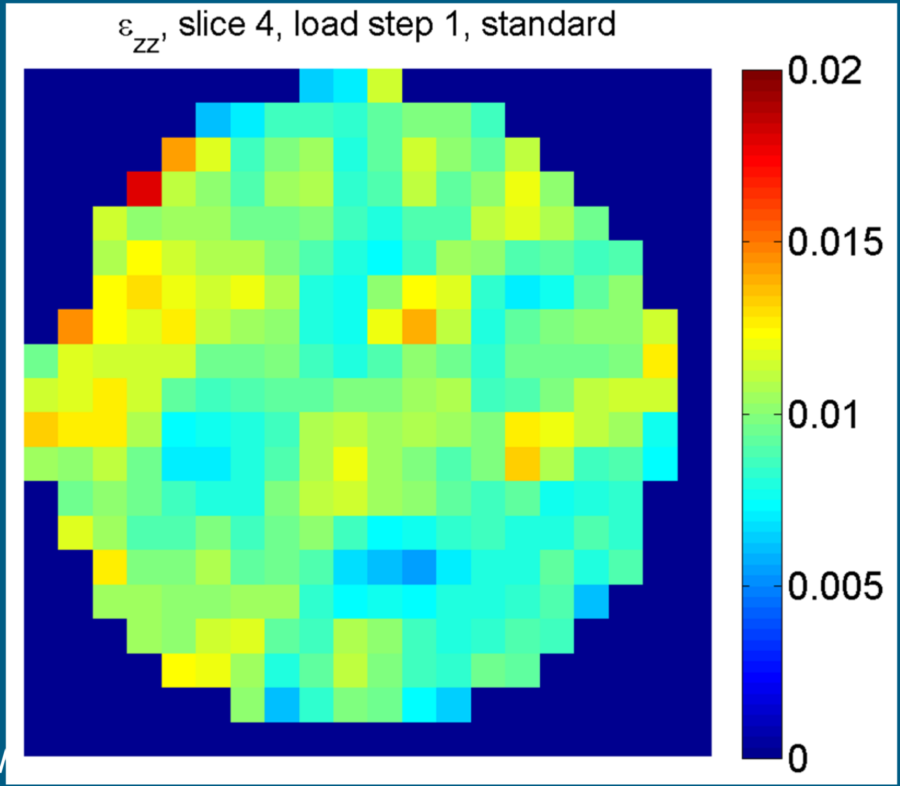


Tensile tests - standard (2/7)

- Imaging and processing parameters
  - 633 x 633 x 558, 15 microns voxel size
  - 64 x 64 x 64, step 50% (32)
  - Final data size: 20 x 20 x 17
  - 3 load steps

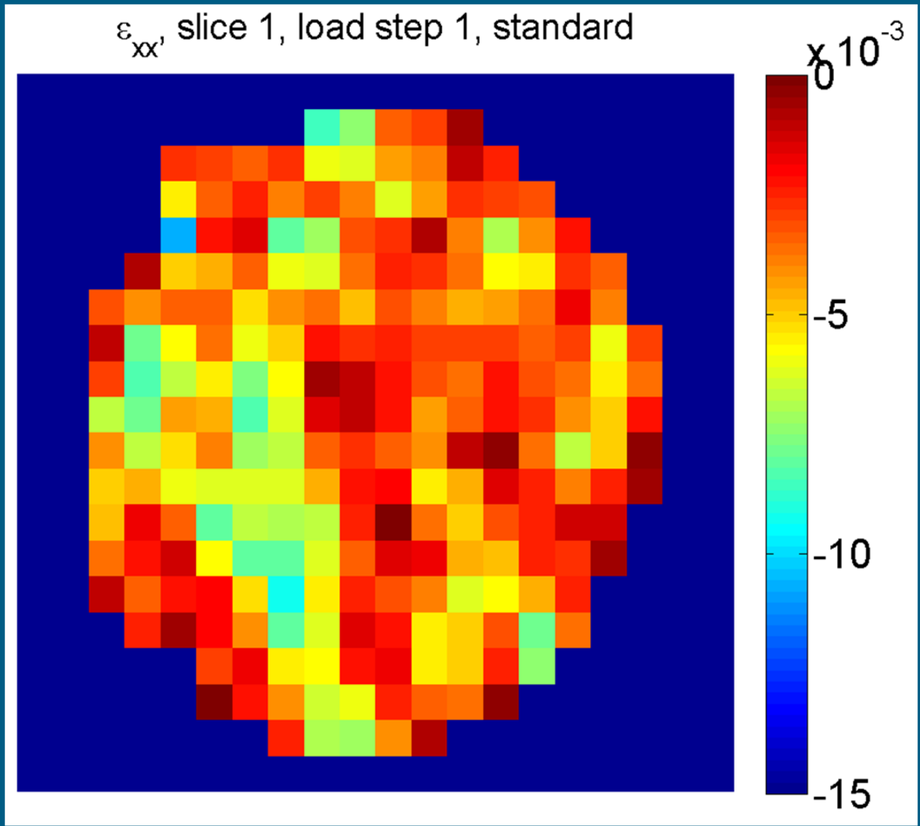
Load step 1

Strain res: 0.0015

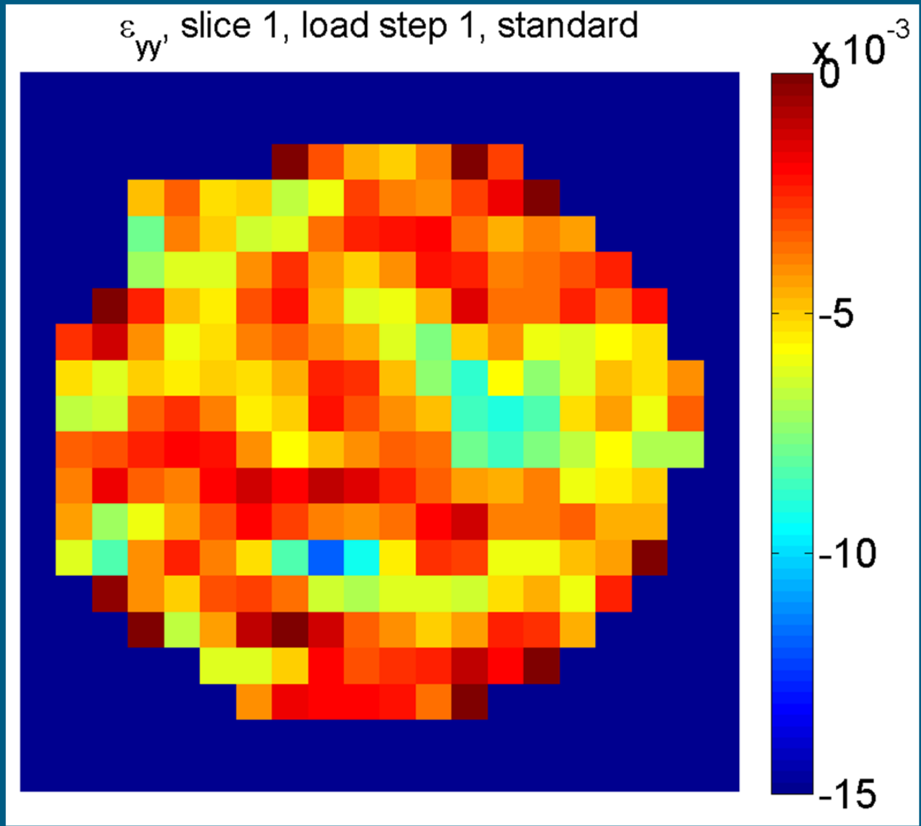


Tensile tests - standard (3/7)

- Transverse strain components



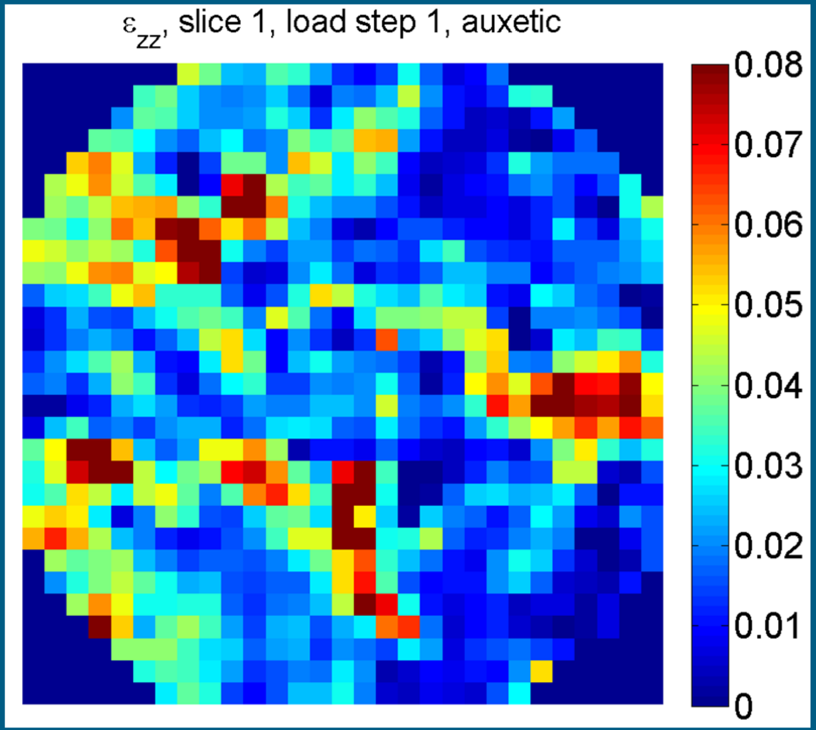
ε_{xx}



ε_{yy}

Tensile tests – auxetic (4/7)

- Imaging and processing parameters
  - 700 x 700 x 676, 15 microns voxel size
  - 48 x 48 x 48, step 50% (24)
  - Final data size: 29 x 29 x 28
  - 2 load steps

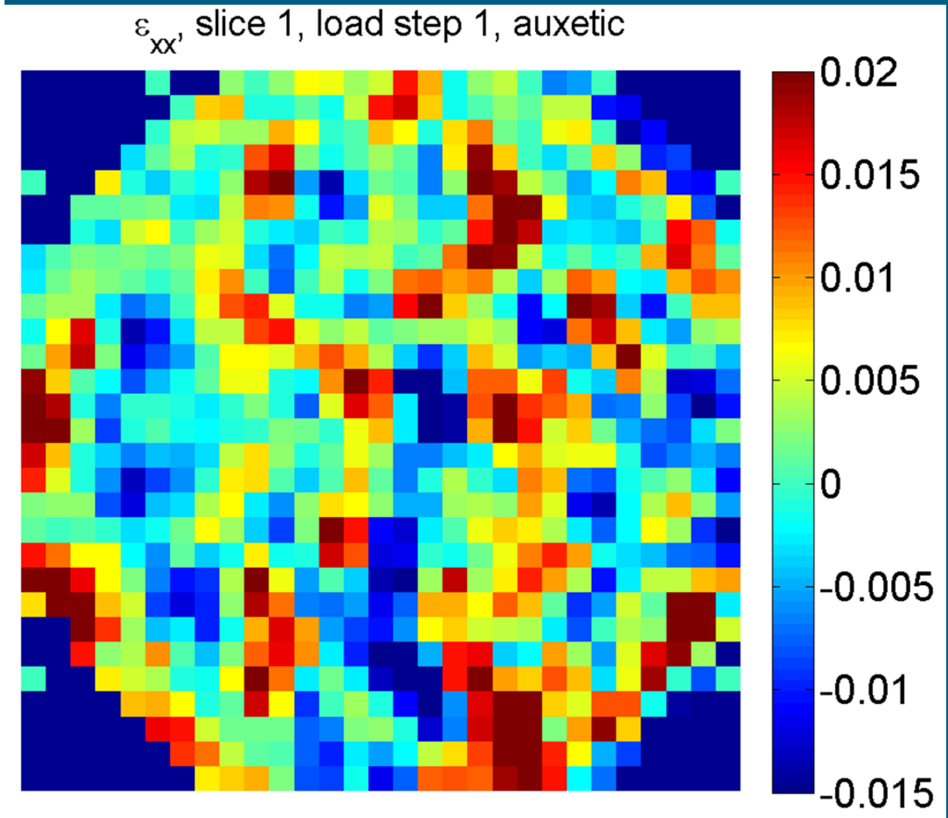


Load step 1

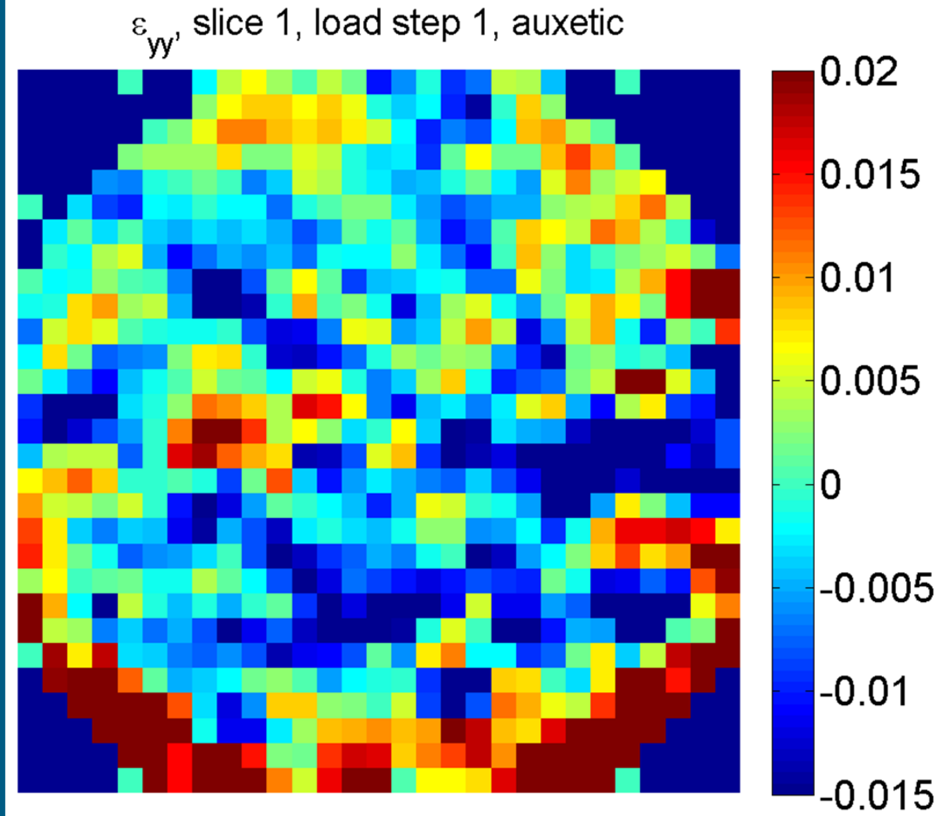
Strain res: 0.0006

Tensile tests – auxetic (5/7)

- Transverse strain components



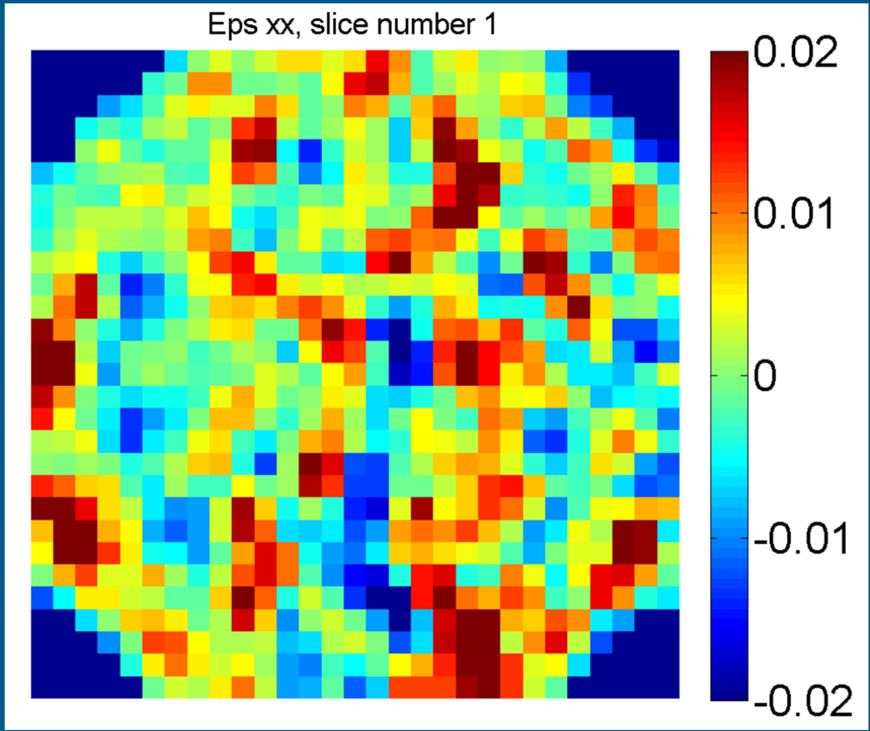
ε_{xx}



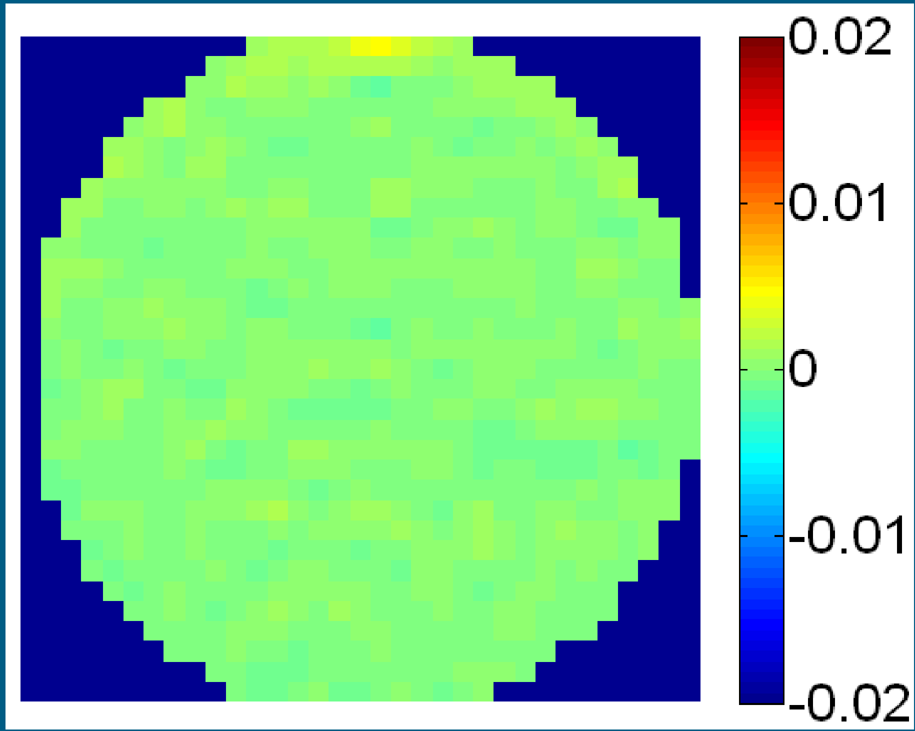
ε_{yy}

Tensile tests – auxetic (6/7)

- Strains in Z-slices
  - Heterogeneous strain field



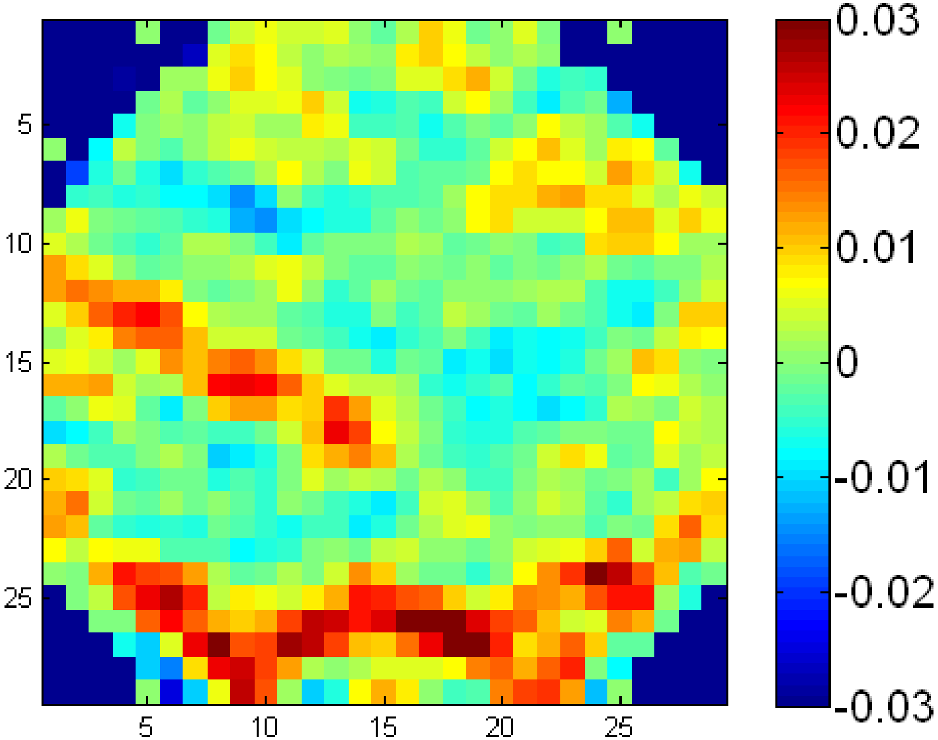
ε_{xx}

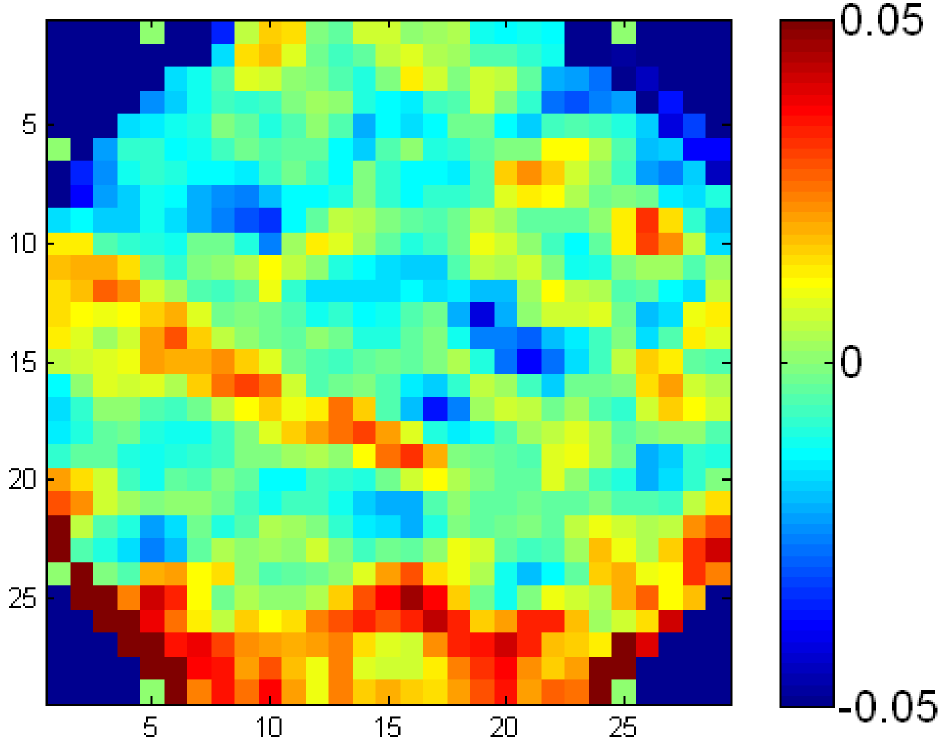


From rigid body motion

Tensile tests – auxetic (7/7)

- Material effect: confirmation
  - Spatial correlation between load steps





A to B

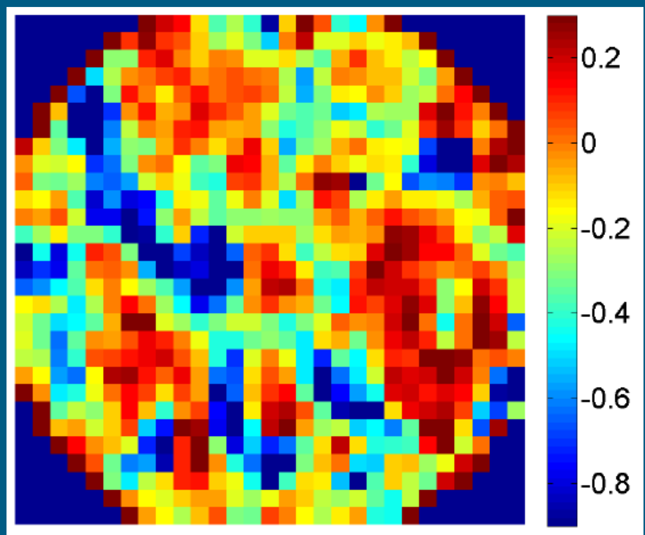
ε_{xx}

B to C

Poisson's ratio (1/7)

- Poisson's ratio calculation: assumption of uniaxial and uniform stress
  - 1st method

$$\nu_{xy}(x,y,z) = -\frac{\varepsilon_{xx}(x,y,z)}{\varepsilon_{zz}(x,y,z)}$$



In a z slice

$$\nu_{xy}^{1}(z) = -\overline{\left[\frac{\varepsilon_{xx}(x,y,z)}{\varepsilon_{zz}(x,y,z)}\right]}$$

Poisson's ratio (2/7)

- Poisson's ratio calculation: assumption of uniaxial and uniform stress
  - 2nd method

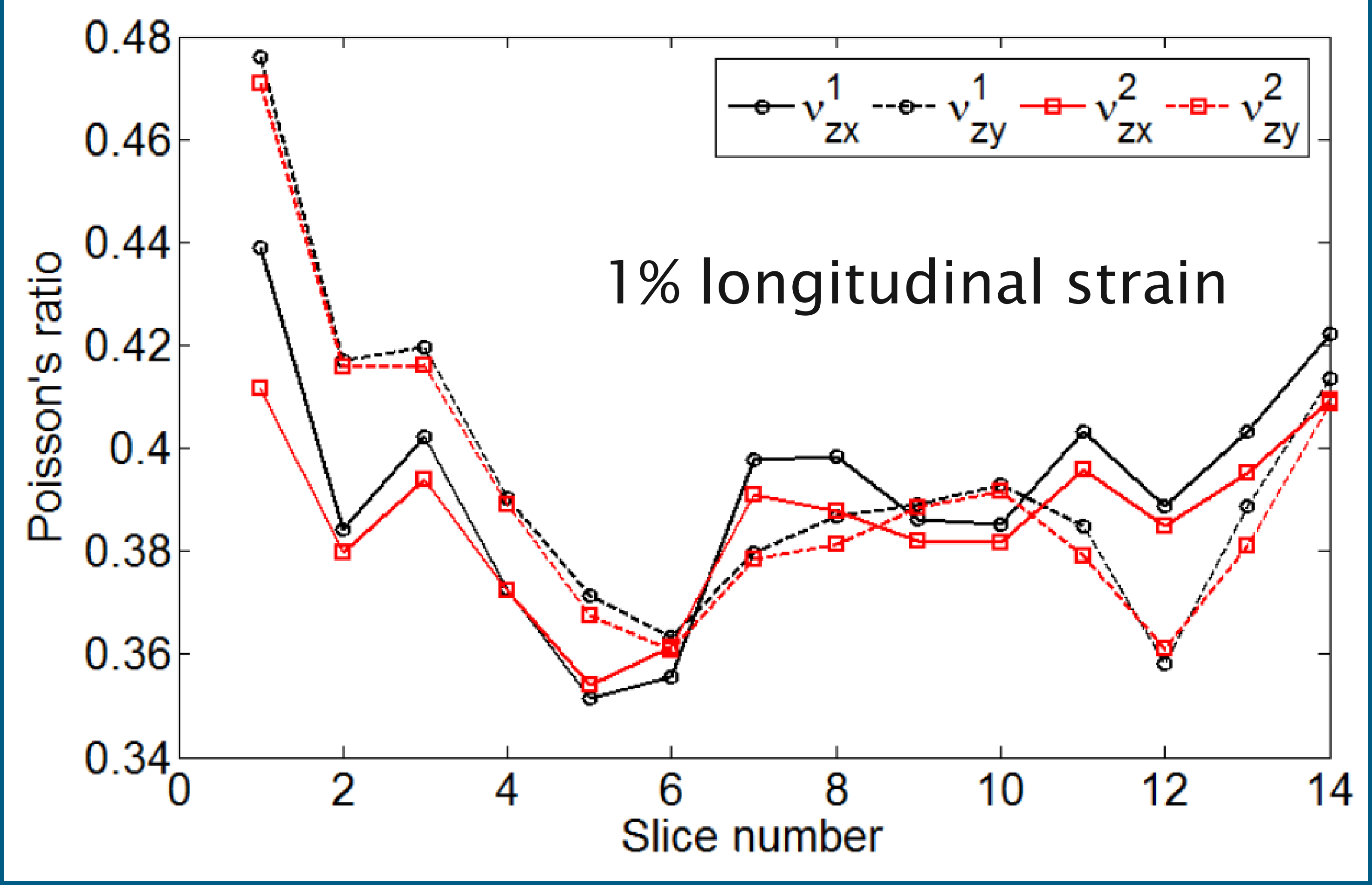
$$\nu_{xy}^{2}(z) = -\frac{\overline{\varepsilon_{xx}(x,y,z)}}{\overline{\varepsilon_{zz}(x,y,z)}}$$

- For homogeneous materials and no noise

$$\nu_{xy}^{1}(z) = \nu_{xy}^{2}(z)$$

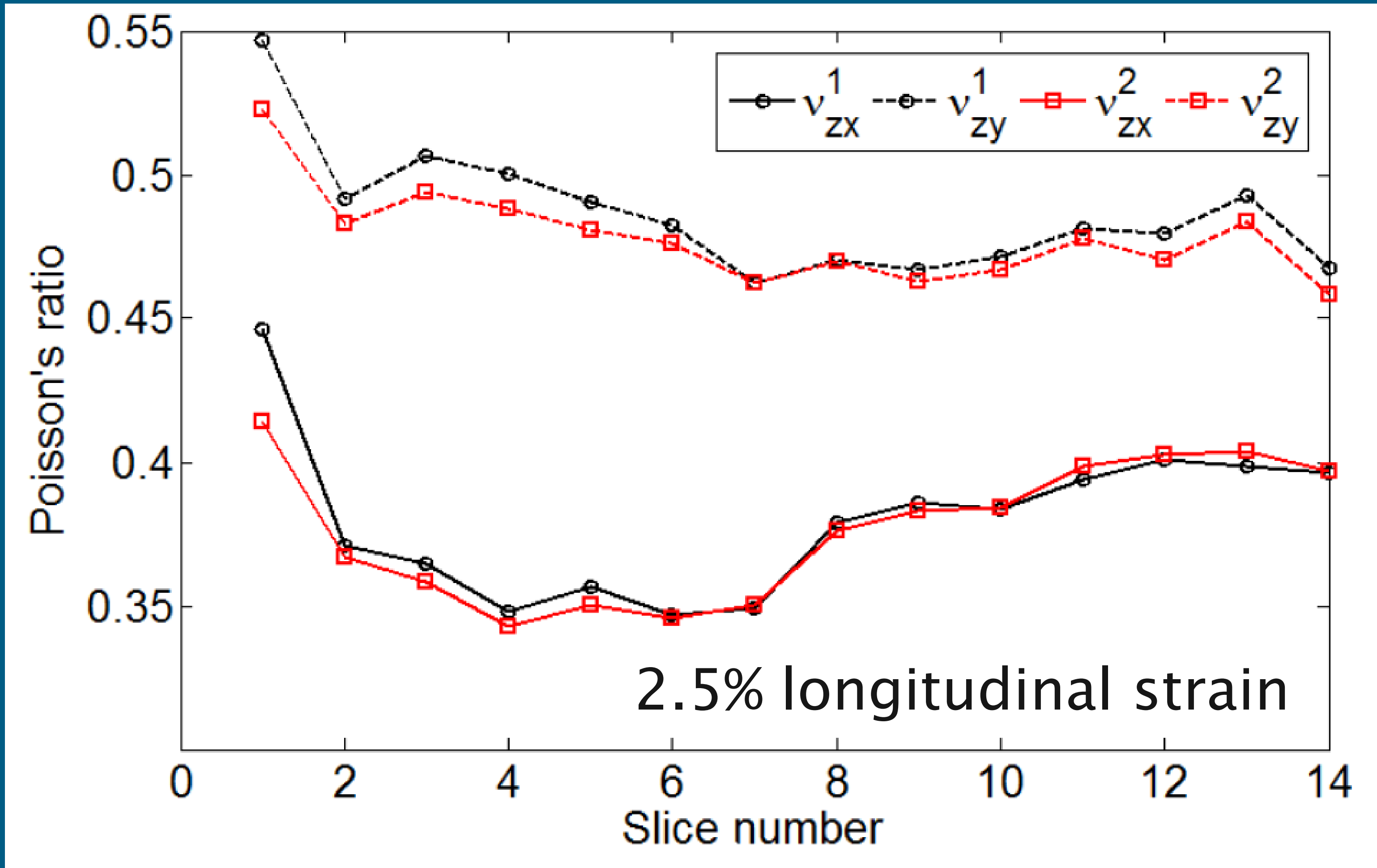
Poisson's ratio - standard (3/7)

- Load step 1



Poisson's ratio - standard (4/7)

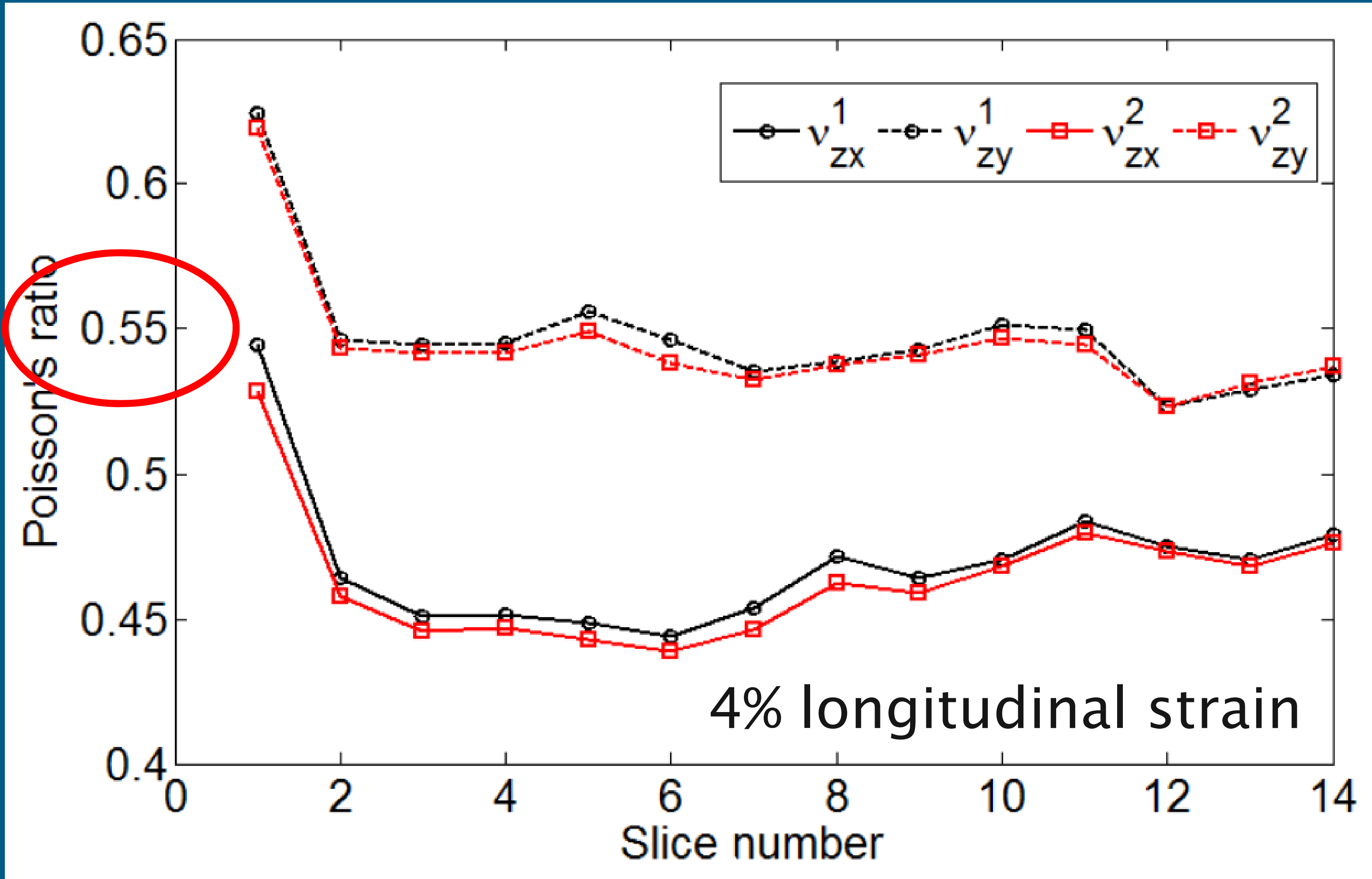
- Load step 2



Poisson's ratio - standard (5/7)

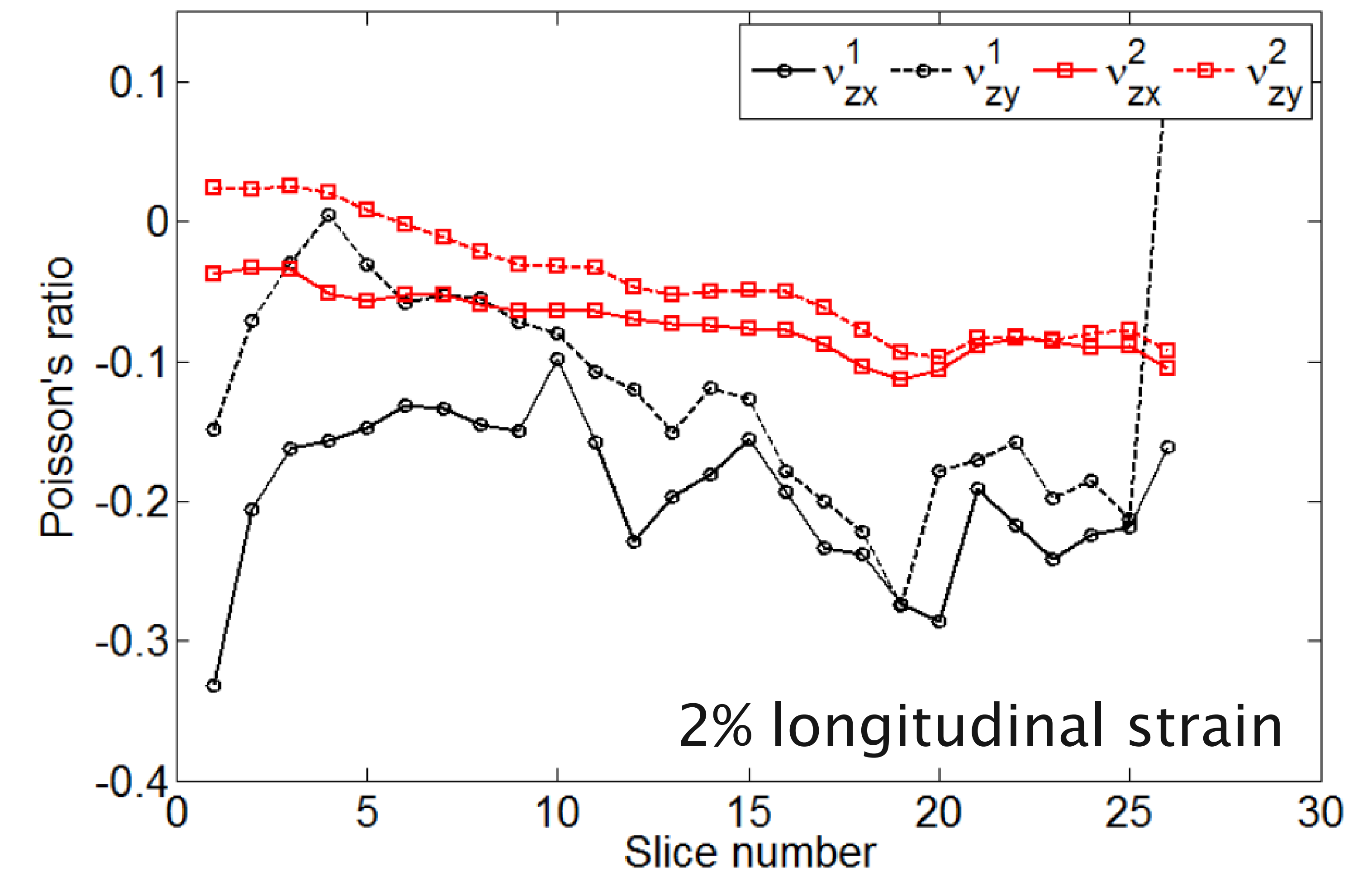
- Load step 3

Induced anisotropy?



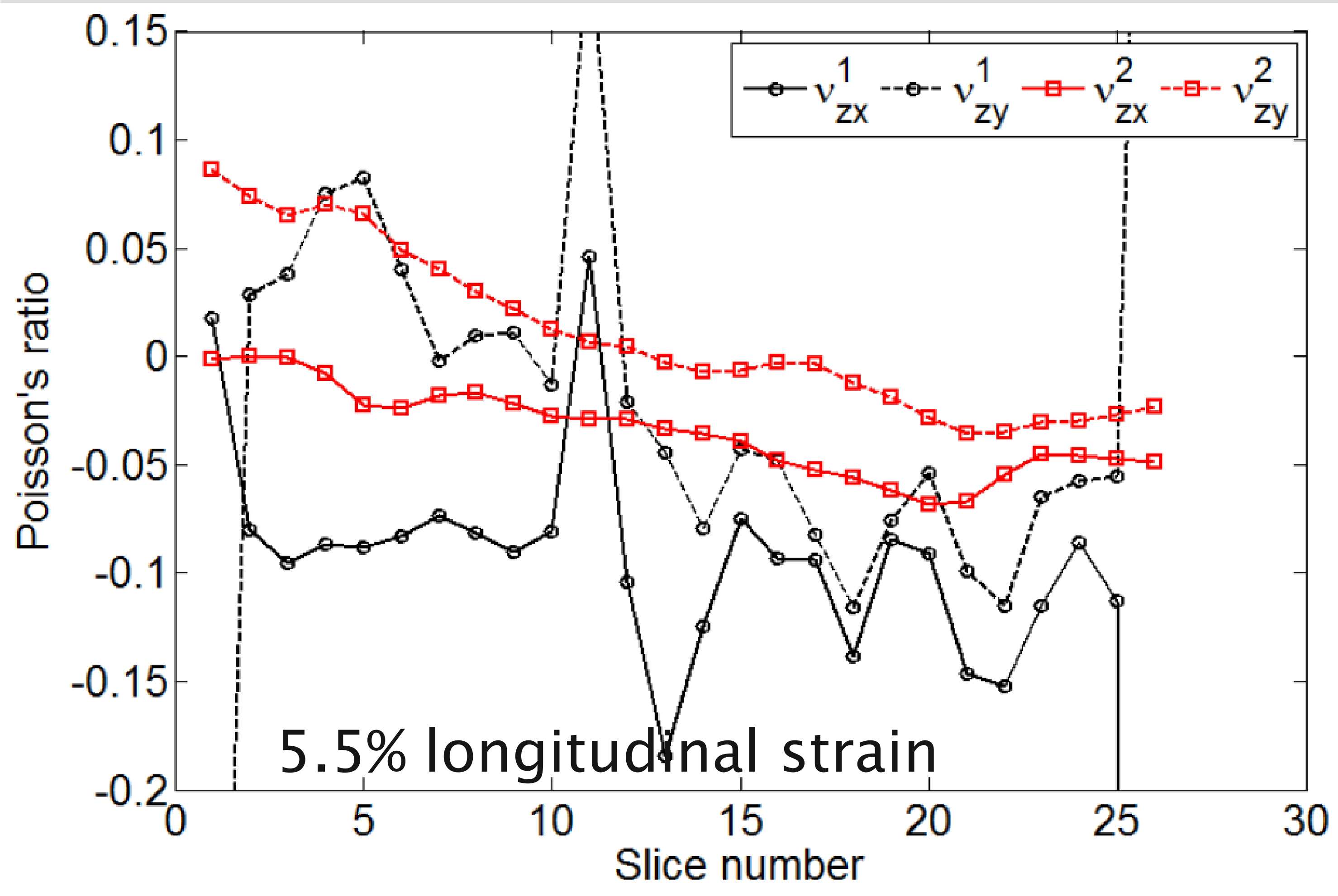
Poisson's ratio - auxetic (6/7)

- Load step 1



Poisson's ratio - auxetic (7/7)

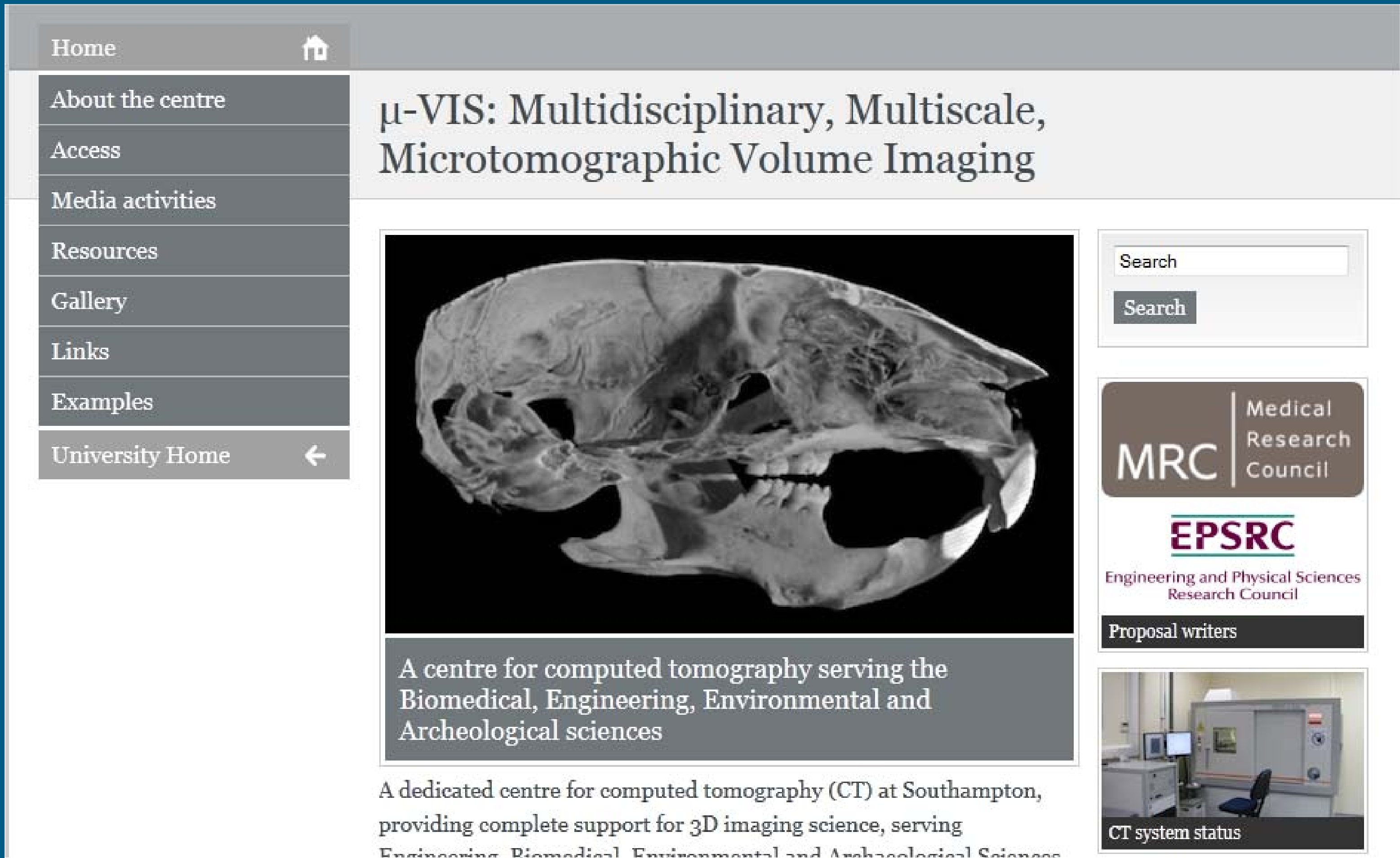
- Load step 2



Conclusions

- DVC is possible on low density polymeric foams from X-ray CT scans
- Strain resolution between 600 and 1500 μstrains, for spatial resolution of 48 to 64 voxel (ie, 0.72 to 0.96 mm)
- Strong heterogeneities in the auxetic foam specimen
  - Intermediate scales (groups of cells)
- Future work
  - Identify constitutive behaviour from complex tests

MuVis X-ray CT center



http://www.southampton.ac.uk/muvis/