Imperial College London

Statistical Characterisation of Porous Media at the Pore Scale

Parametric Models

Student:

Lukas Mosser

Supervisors:

Professor Olivier Dubrule

Professor Martin Blunt

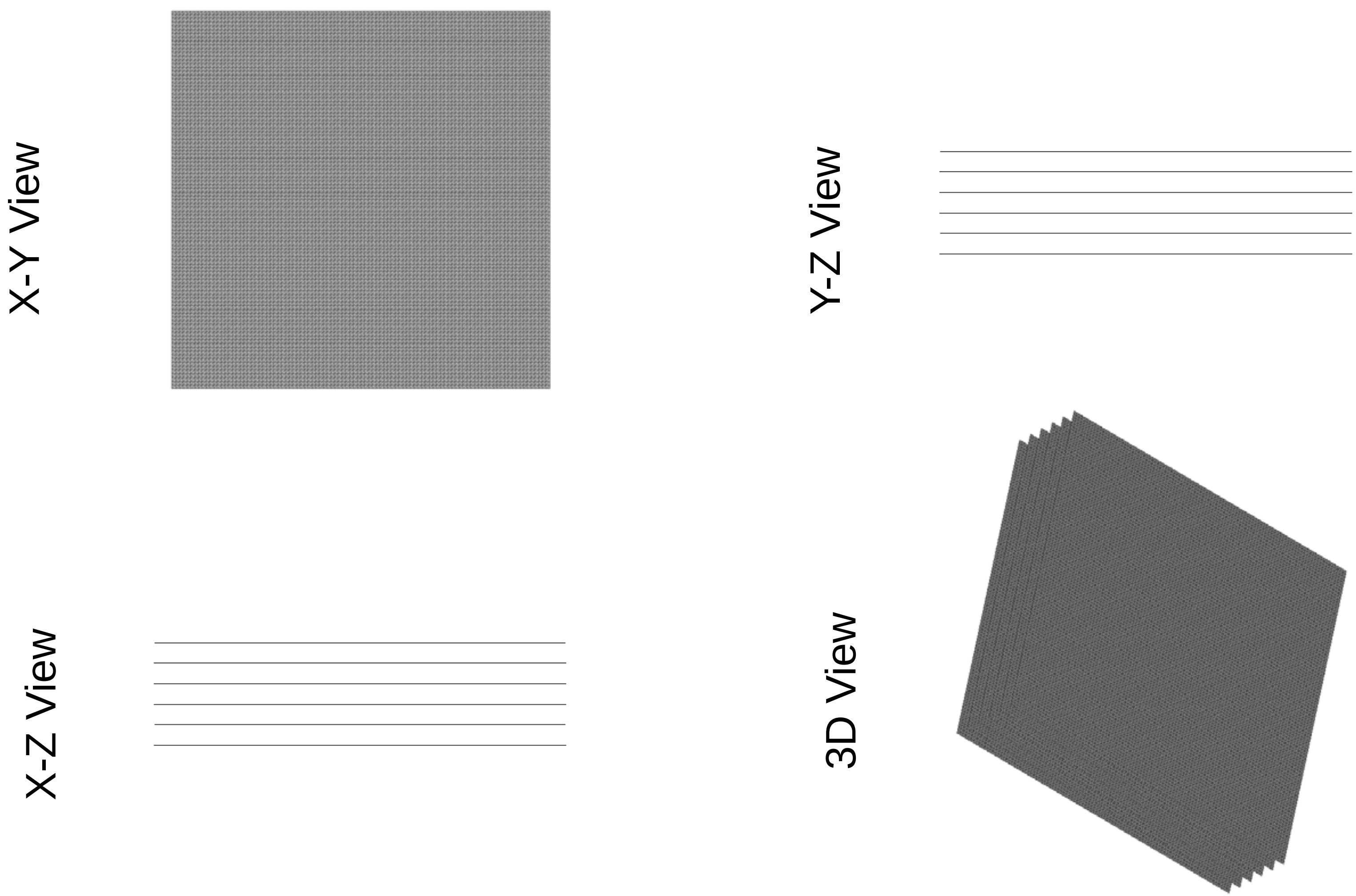
Imperial College London

Presentation Outline

- Plane Surface
- Regular Bundle of Tubes
- Regular Bundle of Tubes – High Mesh Res.
- Random Bundle of Tubes
- Array of Spheres
- Array of Ellipsoids
- Gaussian Porous Medium
- Beadpack: Anisotropy(r)
- Ketton: Anisotropy(r)
- Comparison Beadpack - Ketton

Imperial College London

Plane Surfaces

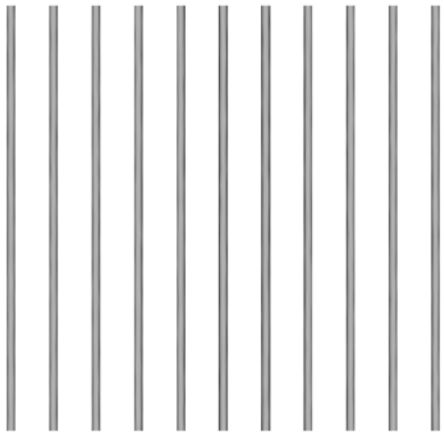


Minkowski Tensors – Plane Surface

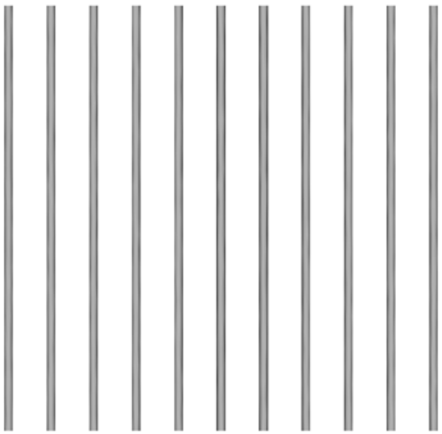
Minkowski Tensor	Eigenvectors	Eigenvalues	Anisotropy Index
$W_1^{0,2} = \begin{bmatrix} 0.0 & 0 & 0 \\ 0 & 0.0 & 0 \\ 0 & 0 & 2400. \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{0.0 \quad 0.0 \quad 2400.\}$	$\beta_1^{0,2} = not\ def.$
$W_2^{0,2} = \begin{bmatrix} 0.0 & 0 & 0 \\ 0 & 0.0 & 0 \\ 0 & 0 & 0.0 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{0.0 \quad 0.0 \quad 0.0\}$	$\beta_2^{0,2} = not\ def.$

Regular Bundle of Tubes

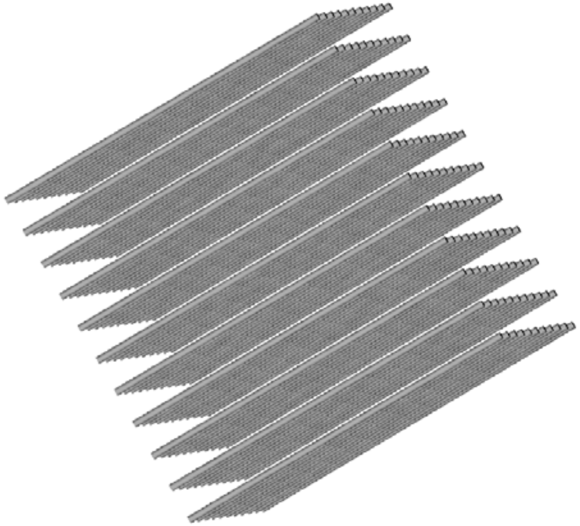
X-Z View



Y-Z View



3D View



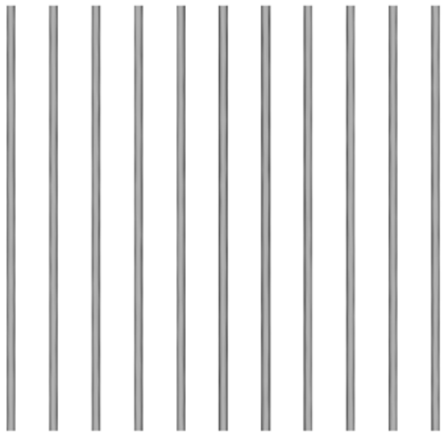
Minkowski Tensors – Regular Bundle of Tubes

Minkowski Tensor	Eigenvectors	Eigenvalues	Anisotropy Index
$W_1^{0,2} = \begin{bmatrix} 12605 & 0 & 0 \\ 0 & 12605 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{12605 \quad 12605 \quad 0\}$	$\beta_1^{0,2} = not\ def.$
$W_2^{0,2} = \begin{bmatrix} 5960 & 1 & 0 \\ 1 & 6334 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{5960 \quad 6334 \quad 0\}$	$\beta_2^{0,2} = not\ def.$

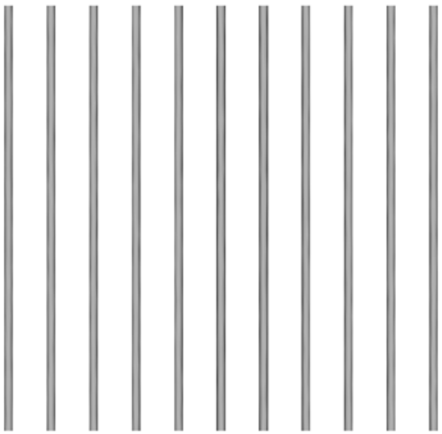
Imperial College London

Regular Bundle of Tubes – High Mesh Resolution

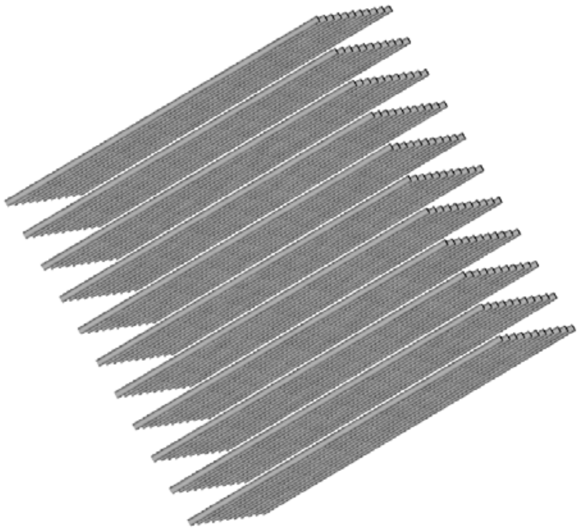
X-Z View



Y-Z View



3D View

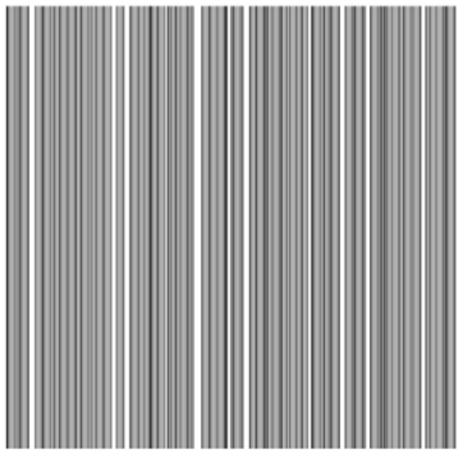


Minkowski Tensors – Regular Bundle – High Mesh Res.

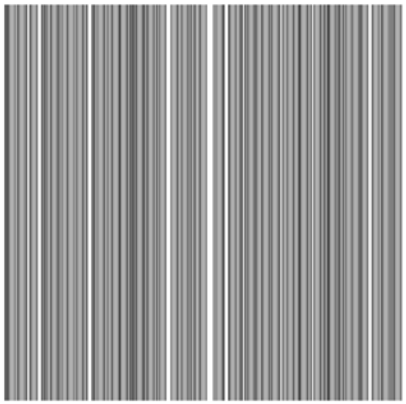
Minkowski Tensor	Eigenvectors	Eigenvalues	Anisotropy Index
$W_1^{0,2} = \begin{bmatrix} 12605 & 0 & 0 \\ 0 & 12605 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{12605 \quad 12605 \quad 0\}$	$\beta_1^{0,2} = not\ def.$
$W_2^{0,2} = \begin{bmatrix} 5960 & 0 & 0 \\ 0 & 6334 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{5960 \quad 6334 \quad 0\}$	$\beta_2^{0,2} = not\ def.$

Random Bundle of Tubes

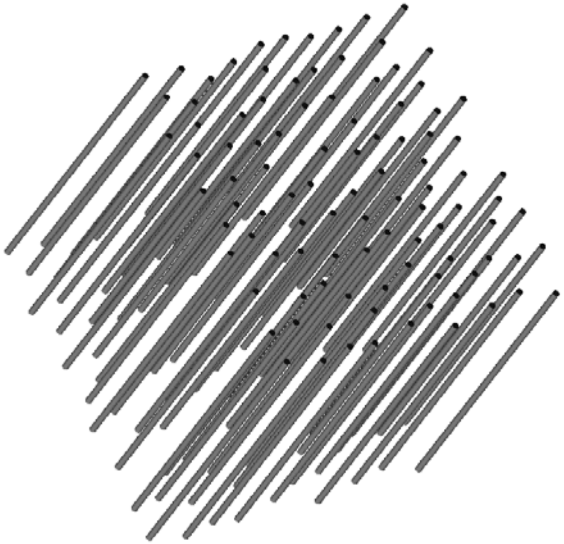
X-Z View



Y-Z View



3D View

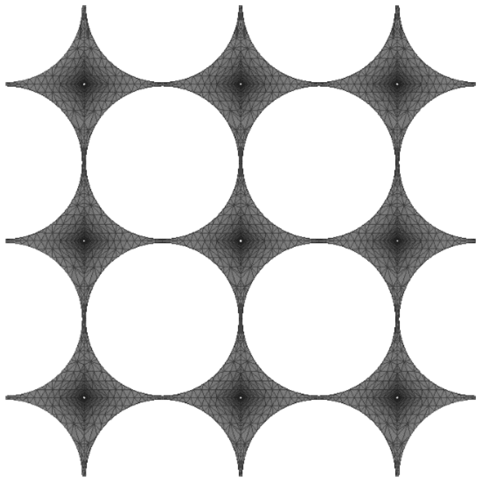


Minkowski Tensors – Random Bundle of Tubes

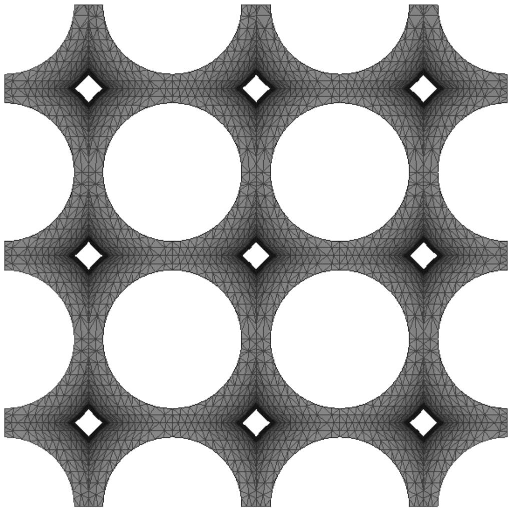
Minkowski Tensor	Eigenvectors	Eigenvalues	Anisotropy Index
$W_1^{0,2} = \begin{bmatrix} 12605 & 0 & 0 \\ 0 & 12605 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{12605 \quad 12605 \quad 0\}$	$\beta_1^{0,2} = not\ def.$
$W_2^{0,2} = \begin{bmatrix} 5960 & 0 & 0 \\ 0 & 6334 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{5960 \quad 6334 \quad 0\}$	$\beta_2^{0,2} = not\ def.$

Symmetric Parametric Pore

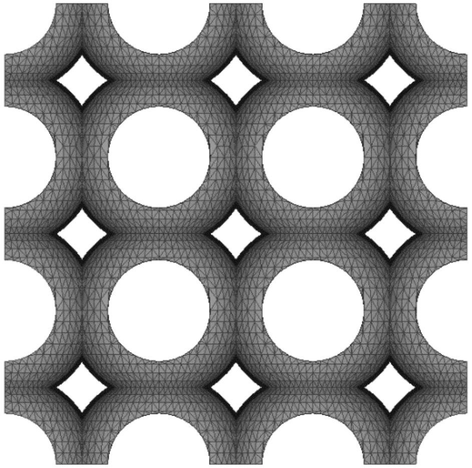
Radius 1.4



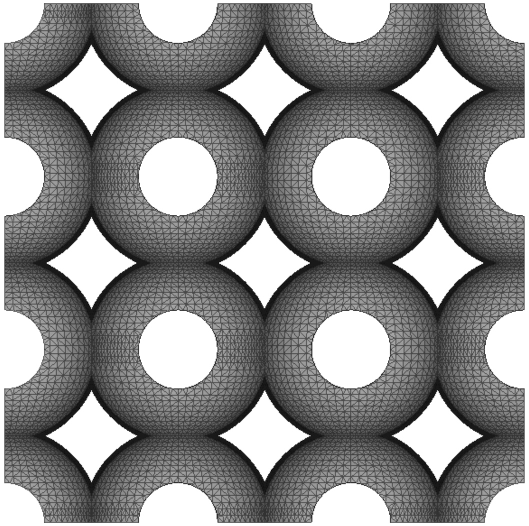
Radius 1.3



Radius 1.2



Radius 1.1



Imperial College London

Minkowski Tensors – Radius 1.4

Minkowski Tensor	Eigenvectors	Eigenvalues	Anisotropy Index
$W_1^{0,2} = \begin{bmatrix} 10.6 & 0 & 0 \\ 0 & 10.6 & 0 \\ 0 & 0 & 10.6 \end{bmatrix}$	$\begin{bmatrix} -0.76 \\ 0.66 \\ 0 \end{bmatrix} \begin{bmatrix} 0.66 \\ -0.76 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{10.6 \quad 10.6 \quad 10.6\}$	$\beta_1^{0,2} = 1.0$
$W_2^{0,2} = \begin{bmatrix} -6.0 & 0 & 0 \\ 0 & -6.0 & 0 \\ 0 & 0 & -6.0 \end{bmatrix}$	$\begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{-6.0 \quad -6.0 \quad -6.0\}$	$\beta_2^{0,2} = 1.0$

Imperial College London

Minkowski Tensors – Radius 1.3

Minkowski Tensor	Eigenvectors	Eigenvalues	Anisotropy Index
$W_1^{0,2} = \begin{bmatrix} 19.6 & 0 & 0 \\ 0 & 19.6 & 0 \\ 0 & 0 & 19.6 \end{bmatrix}$	$\begin{bmatrix} -0.7 \\ 0.7 \\ 0 \end{bmatrix} \begin{bmatrix} 0.7 \\ -0.7 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{19.6 \quad 19.6 \quad 19.6\}$	$\beta_1^{0,2} = 1.0$
$W_2^{0,2} = \begin{bmatrix} -13 & 0 & 0 \\ 0 & -13 & 0 \\ 0 & 0 & -13 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{-13 \quad -13 \quad -13\}$	$\beta_2^{0,2} = 1.0$

Minkowski Tensors – Radius 1.2

Minkowski Tensor	Eigenvectors	Eigenvalues	Anisotropy Index
$W_1^{0,2} = \begin{bmatrix} 27.1 & 0 & 0 \\ 0 & 27.1 & 0 \\ 0 & 0 & 27.1 \end{bmatrix}$	$\begin{bmatrix} -1.0 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1.0 \end{bmatrix} \begin{bmatrix} 0 \\ -1.0 \\ 0 \end{bmatrix}$	$\{27.1 \quad 27.1 \quad 27.1\}$	$\beta_1^{0,2} = 1.0$
$W_2^{0,2} = \begin{bmatrix} -20.7 & 0 & 0 \\ 0 & -20.7 & 0 \\ 0 & 0 & -20.7 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix} \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix}$	$\{-20.7 \quad -20.7 \quad -20.7\}$	$\beta_2^{0,2} = 1.0$

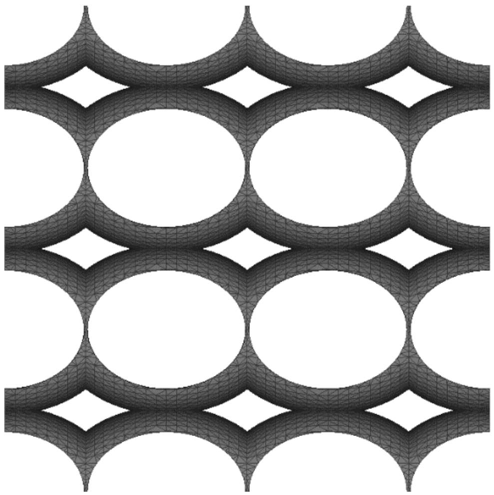
Minkowski Tensors – Radius 1.1

Minkowski Tensor	Eigenvectors	Eigenvalues	Anisotropy Index
$W_1^{0,2} = \begin{bmatrix} 33.1 & 0 & 0 \\ 0 & 33.1 & 0 \\ 0 & 0 & 33.1 \end{bmatrix}$	$\begin{bmatrix} -0.89 \\ 0.45 \\ 0 \end{bmatrix} \begin{bmatrix} 0.45 \\ -0.89 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{33.1 \quad 33.1 \quad 33.1\}$	$\beta_1^{0,2} = 1.0$

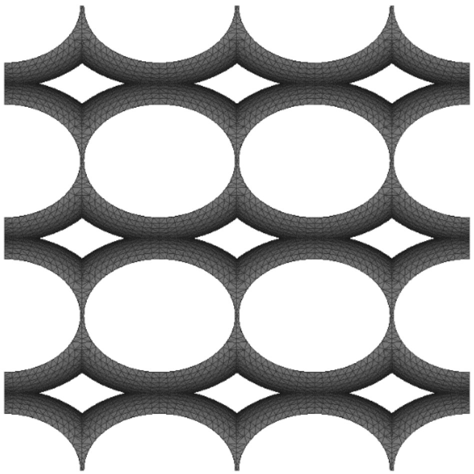
Imperial College
London

Asymmetric Parametric Pore – R1 = 1.4, R2=1.3

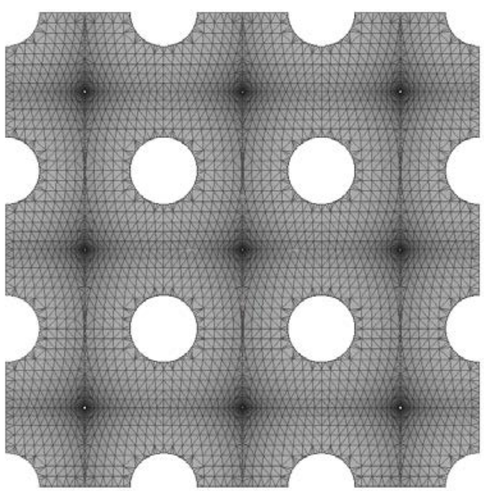
X-Y View



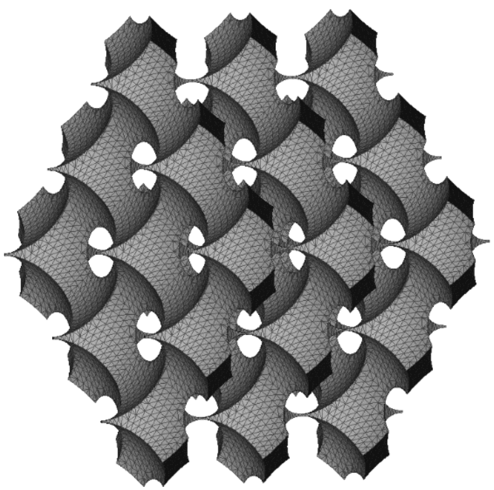
Y-Z View



X-Z View



3D View



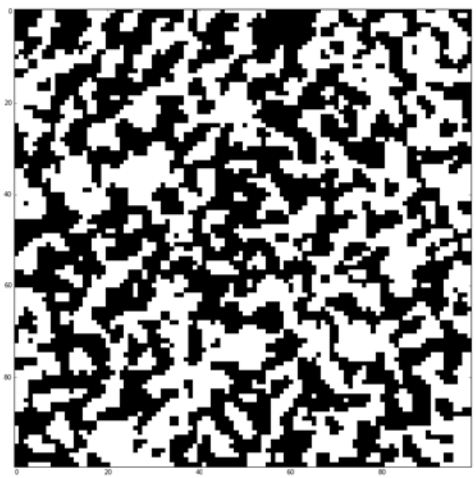
Imperial College London

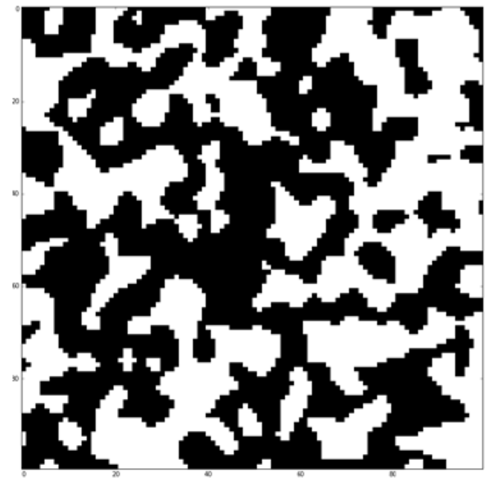
Minkowski Tensors – R1 = 1.4, R2=1.3

Minkowski Tensor	Eigenvectors	Eigenvalues	Anisotropy Index
$W_1^{0,2} = \begin{bmatrix} 11.9 & 0 & 0 \\ 0 & 51.8 & 0 \\ 0 & 0 & 11.9 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{11.9 \quad 51.8 \quad 11.9\}$	$\beta_1^{0,2} = 0.23$
$W_2^{0,2} = \begin{bmatrix} -7.8 & 0 & 0 \\ 0 & -30.9 & 0 \\ 0 & 0 & -7.6 \end{bmatrix}$	$\begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\{-7.8 \quad -30.9 \quad -7.8\}$	$\beta_2^{0,2} = 0.25$

Gaussian Porous Medium – 100^3

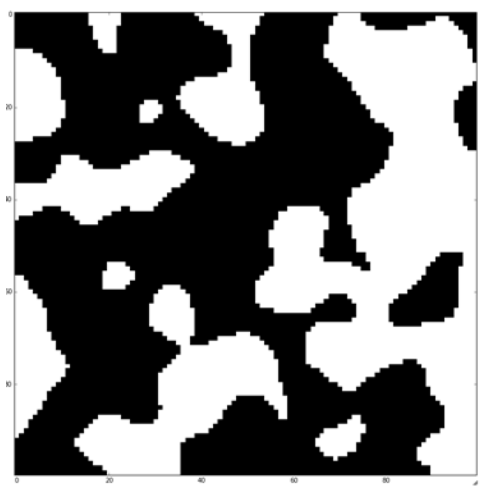
$\sigma = 1.0$

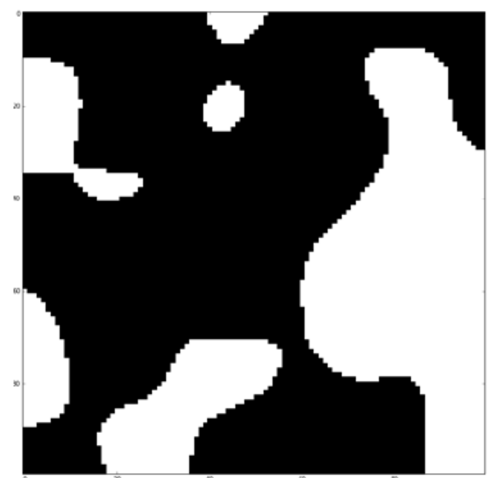




$\sigma = 2.0$

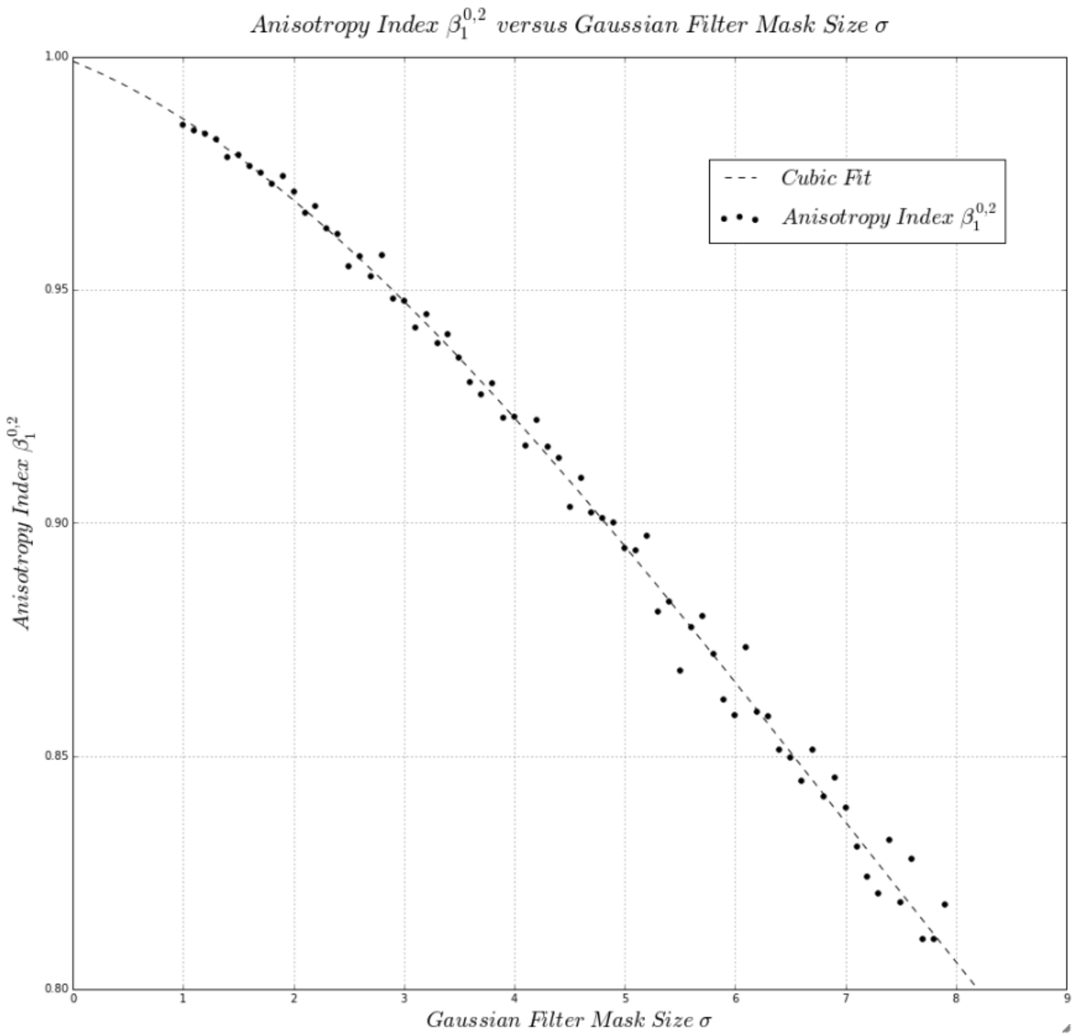
$\sigma = 4.0$





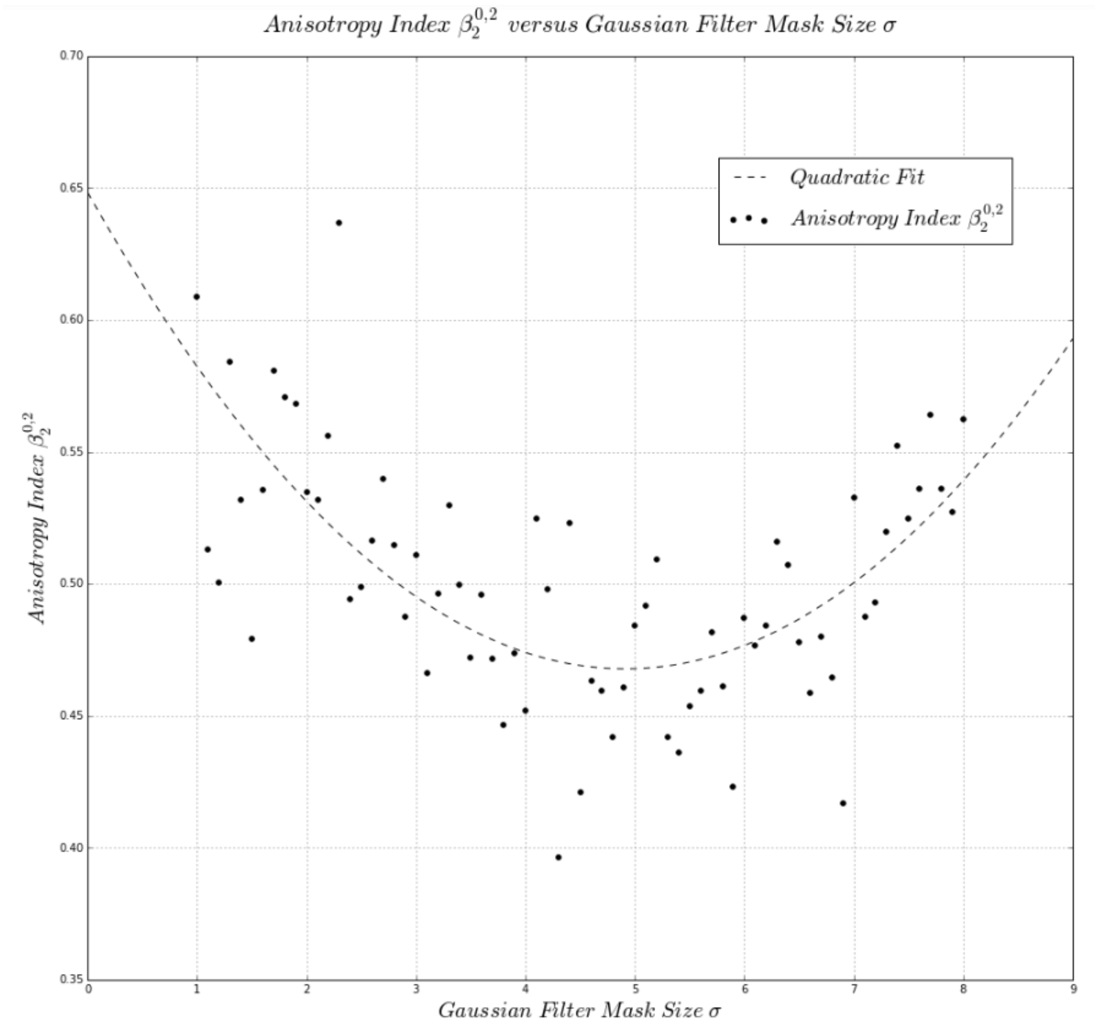
$\sigma = 8.0$

Anisotropy Index as function of filter size (W102)



Imperial College London

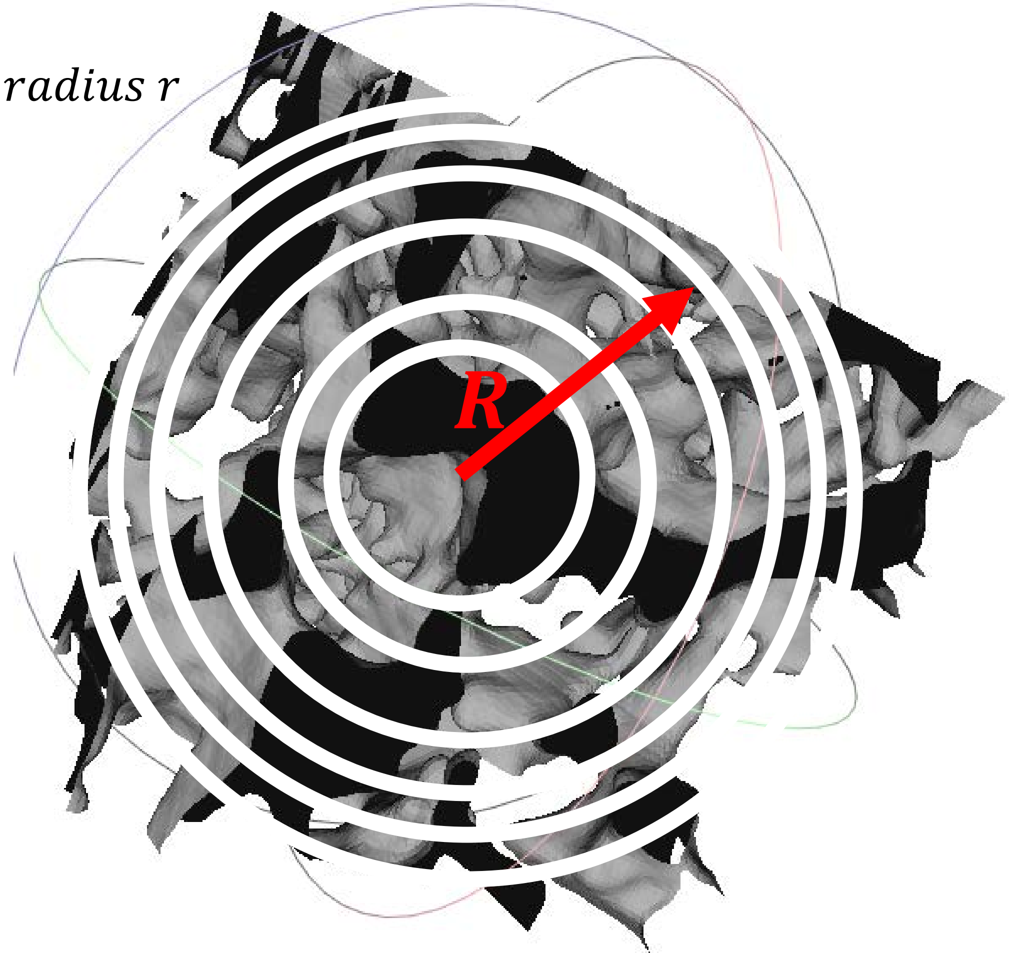
Anisotropy Index as function of filter size (W202)



Beadpack/Ketton

Centered Expanding Window => REV – 500^3

Increasing Window of radius r

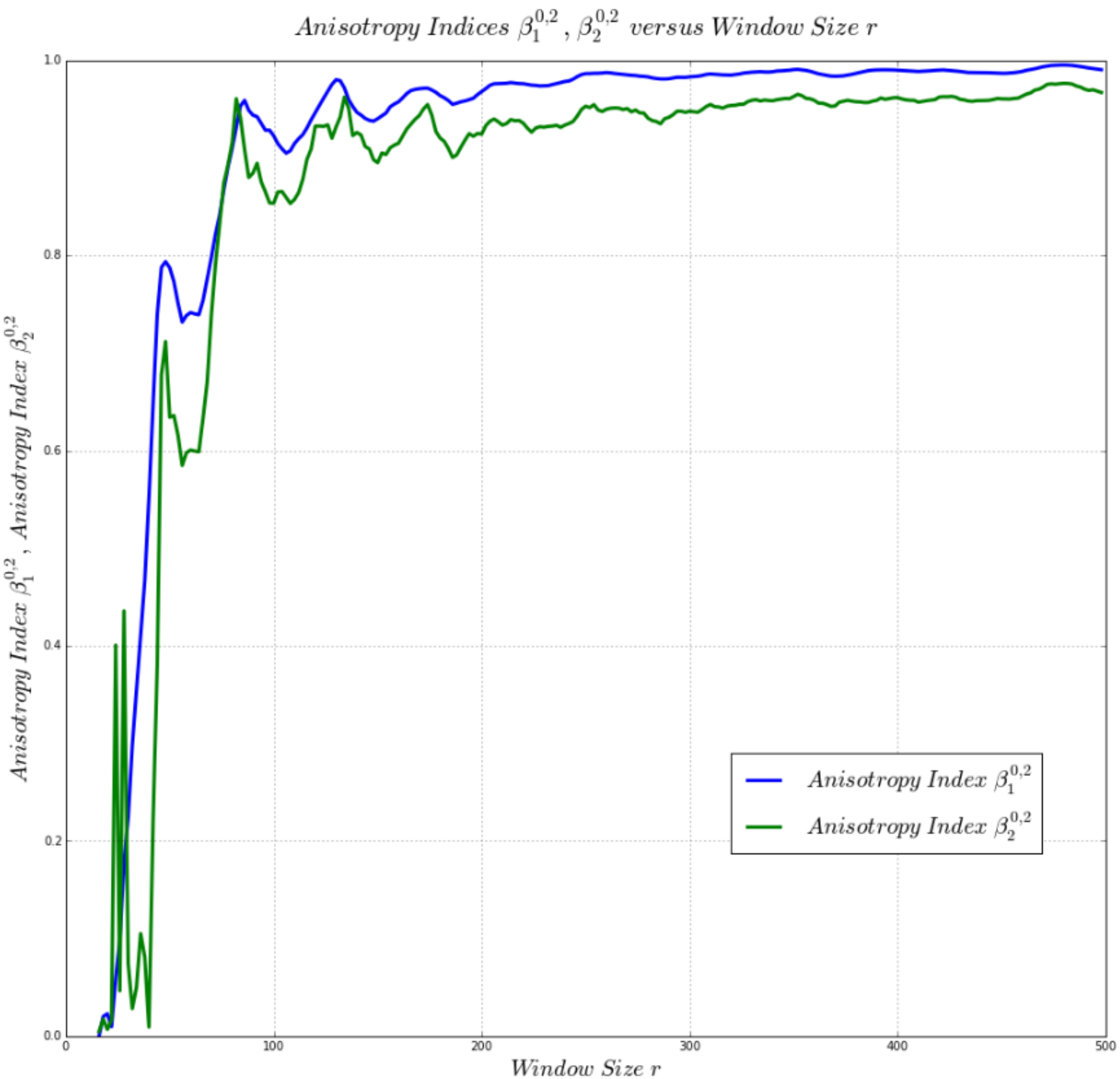


Cubic Volume used

Determine Anisotropy as function of Window Size

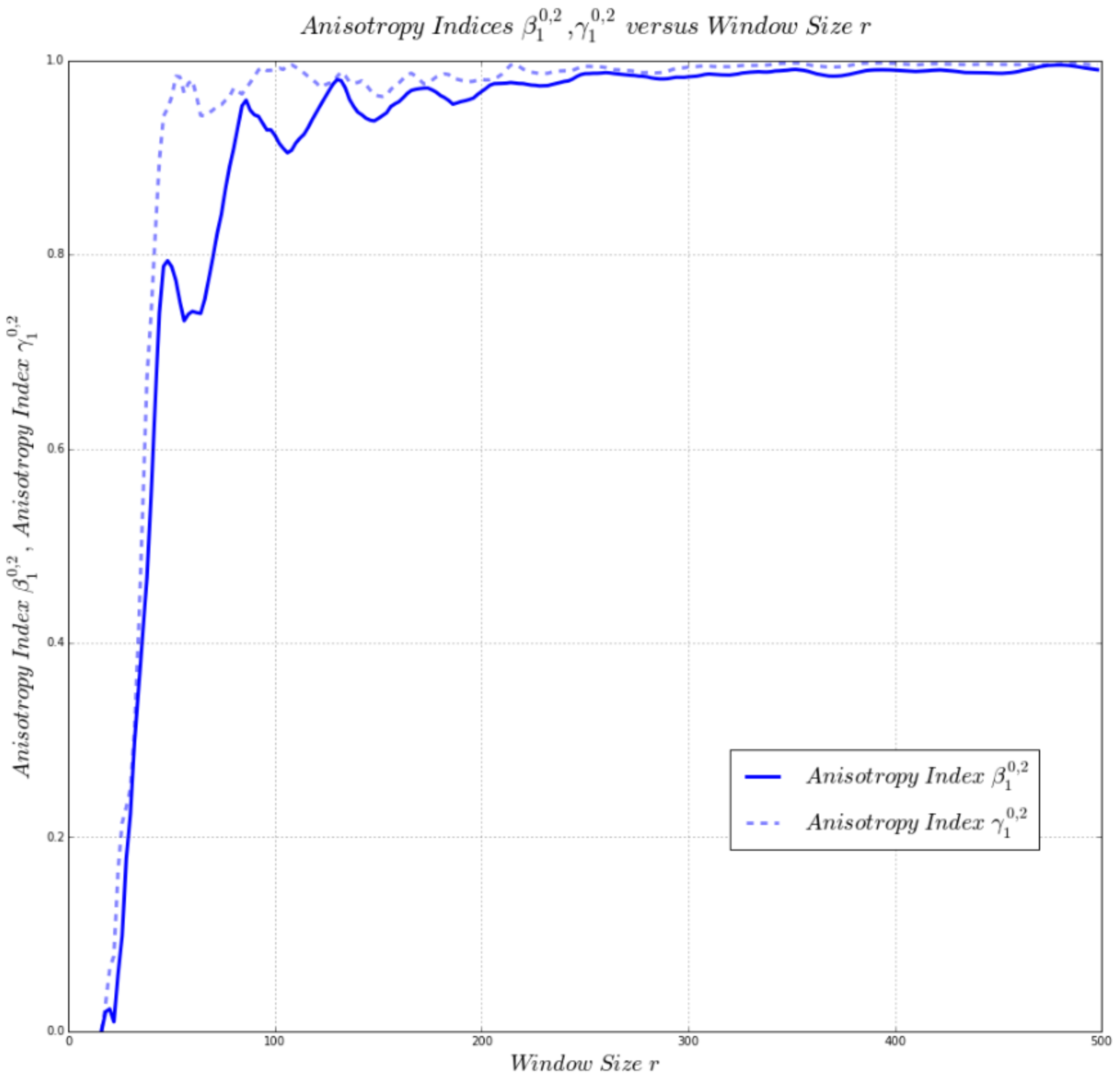
Imperial College London

Beadpack – Centered Expanding Window => REV – 500^3

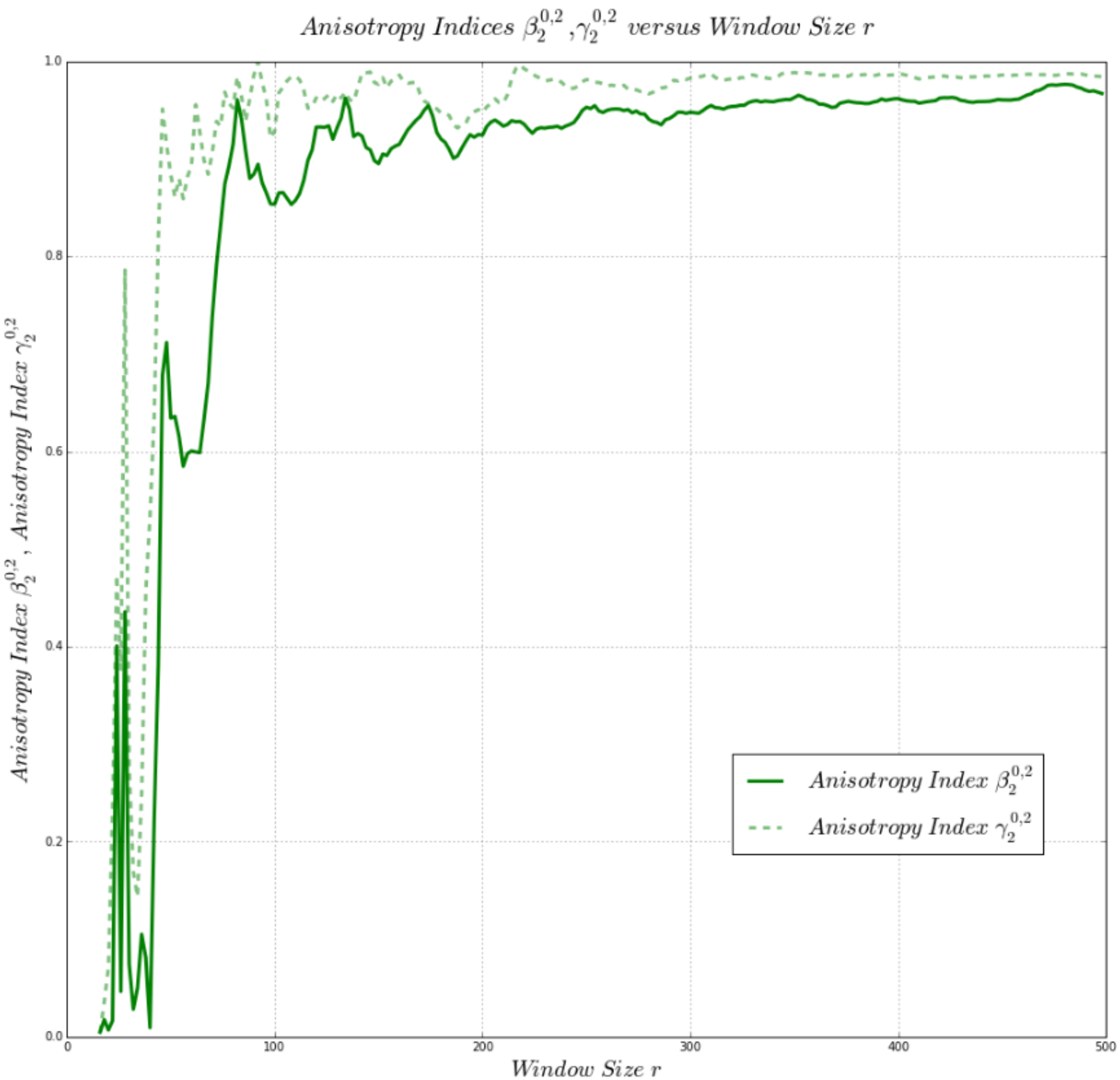


Imperial College London

Beadpack – Centered Expanding Window => REV – 500^3

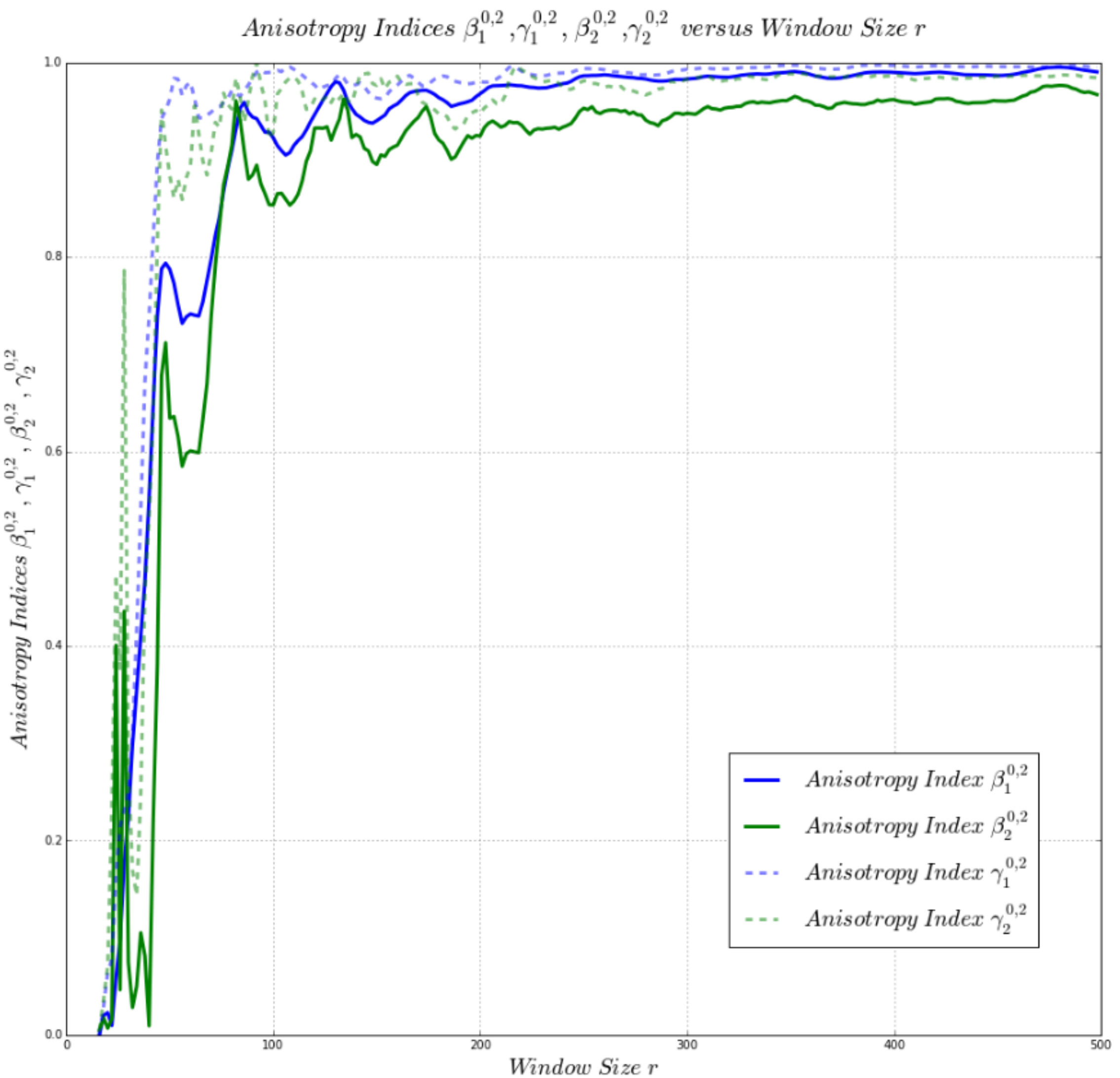


Beadpack – Centered Expanding Window => REV – 500^3



Imperial College London

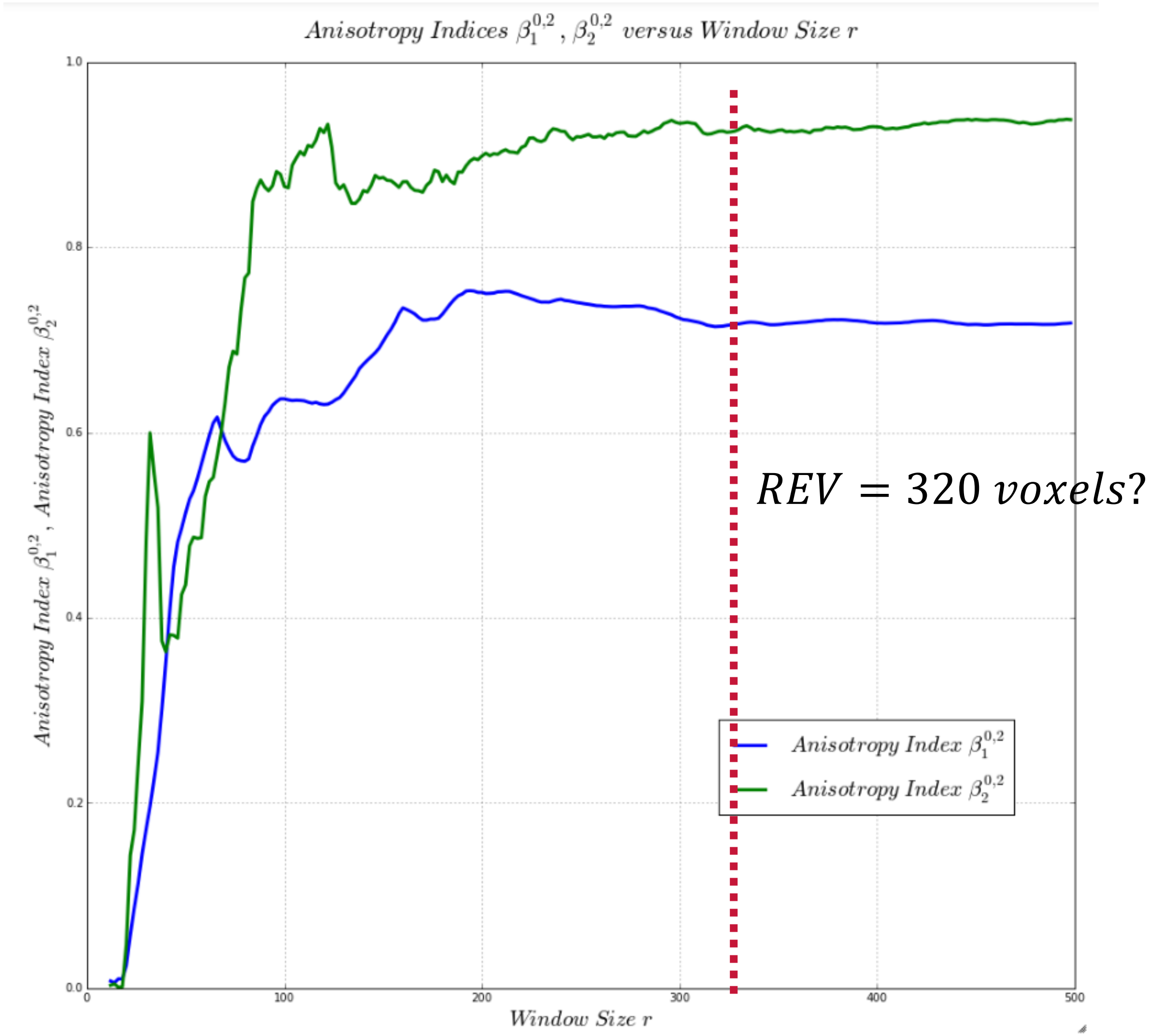
Beadpack – Centered Expanding Window => REV – 500^3



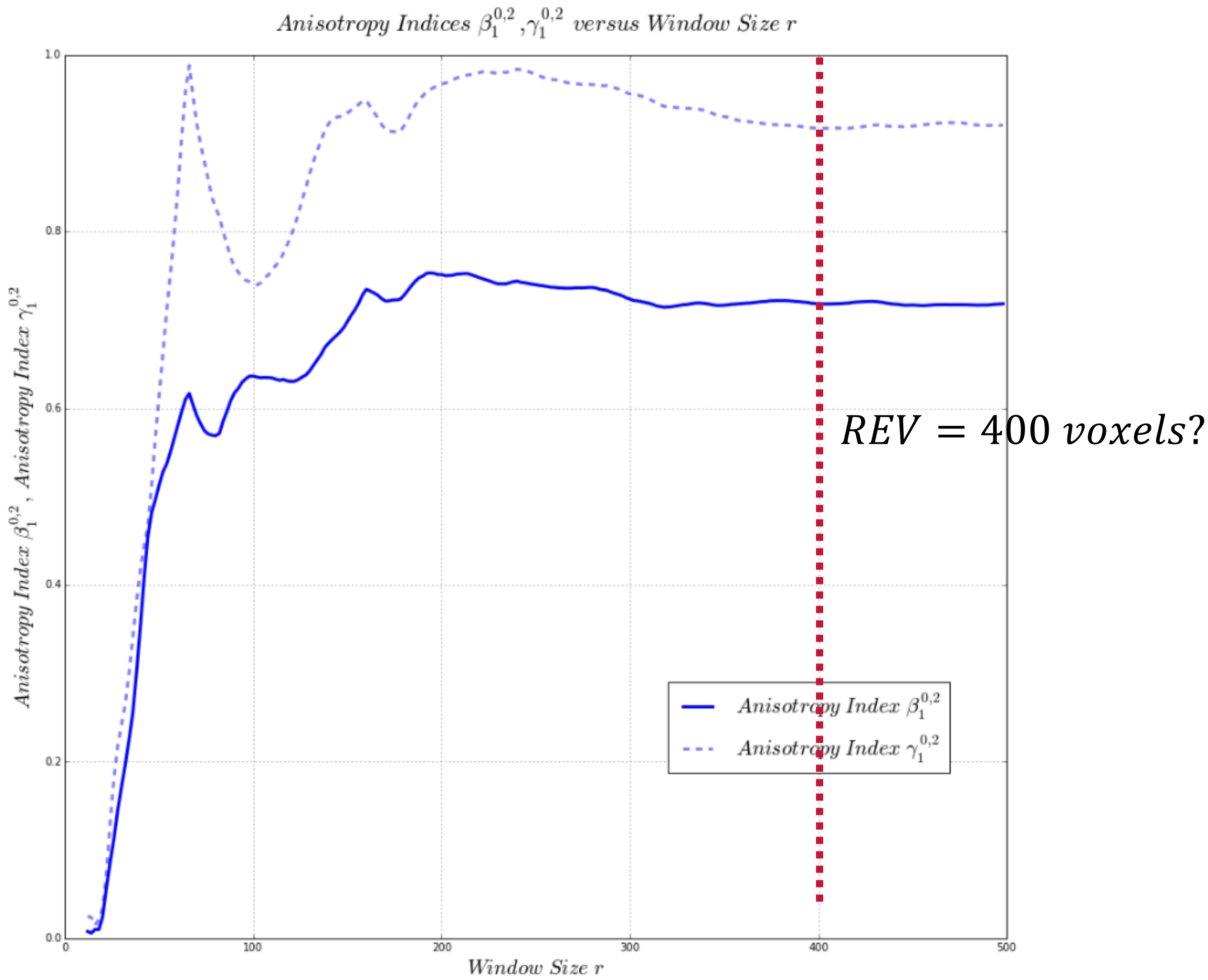
Ketton – Centered Expanding Window

$$Ketton\ Centered\ Expanding\ Window$$

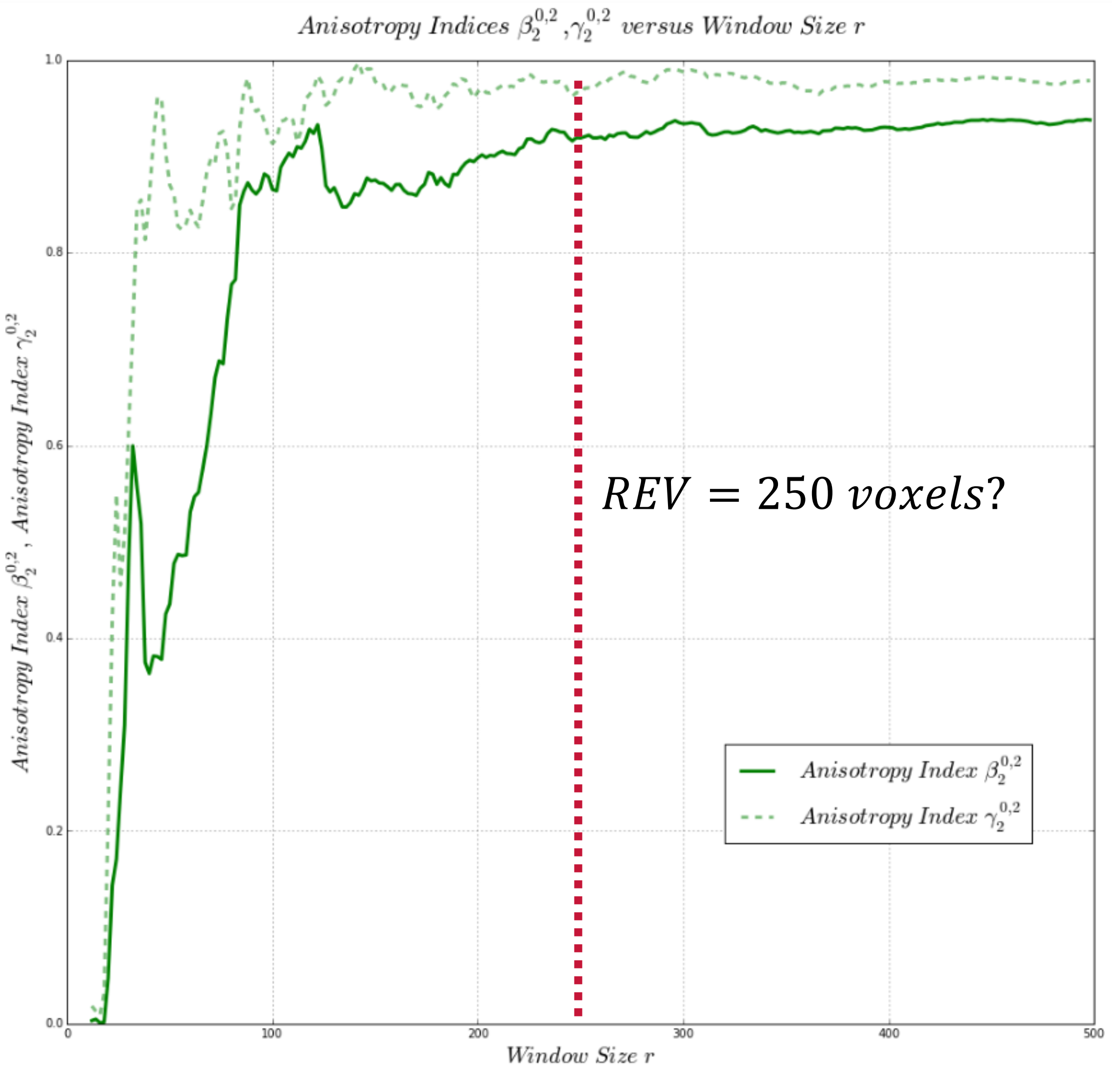
Ketton – Comparison Anisotropy Indices B102, B202



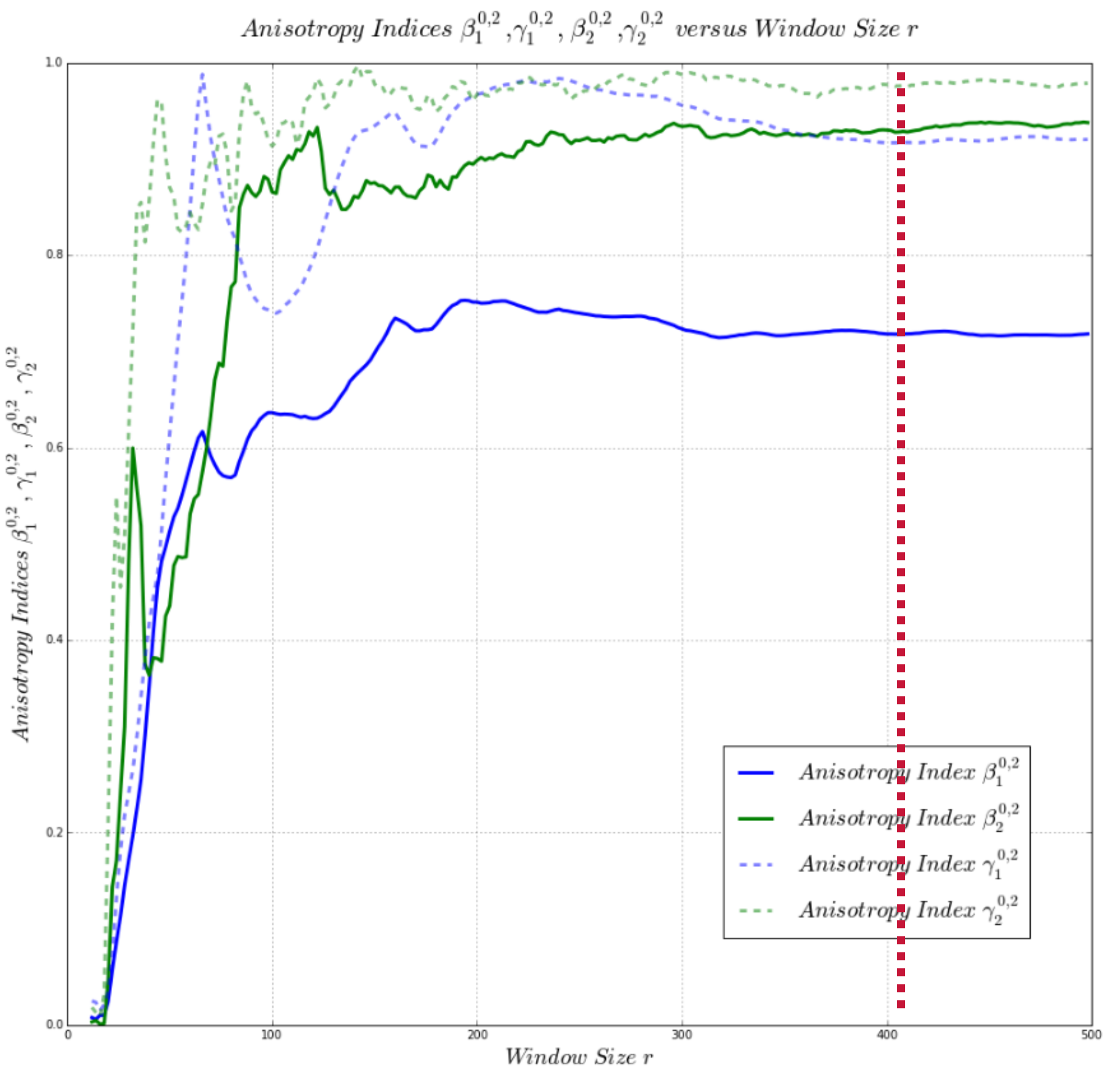
Ketton – Centered Expanding Window => REV – 500^3



Ketton – Centered Expanding Window => REV – 500^3



Ketton – Centered Expanding Window => REV – 500^3



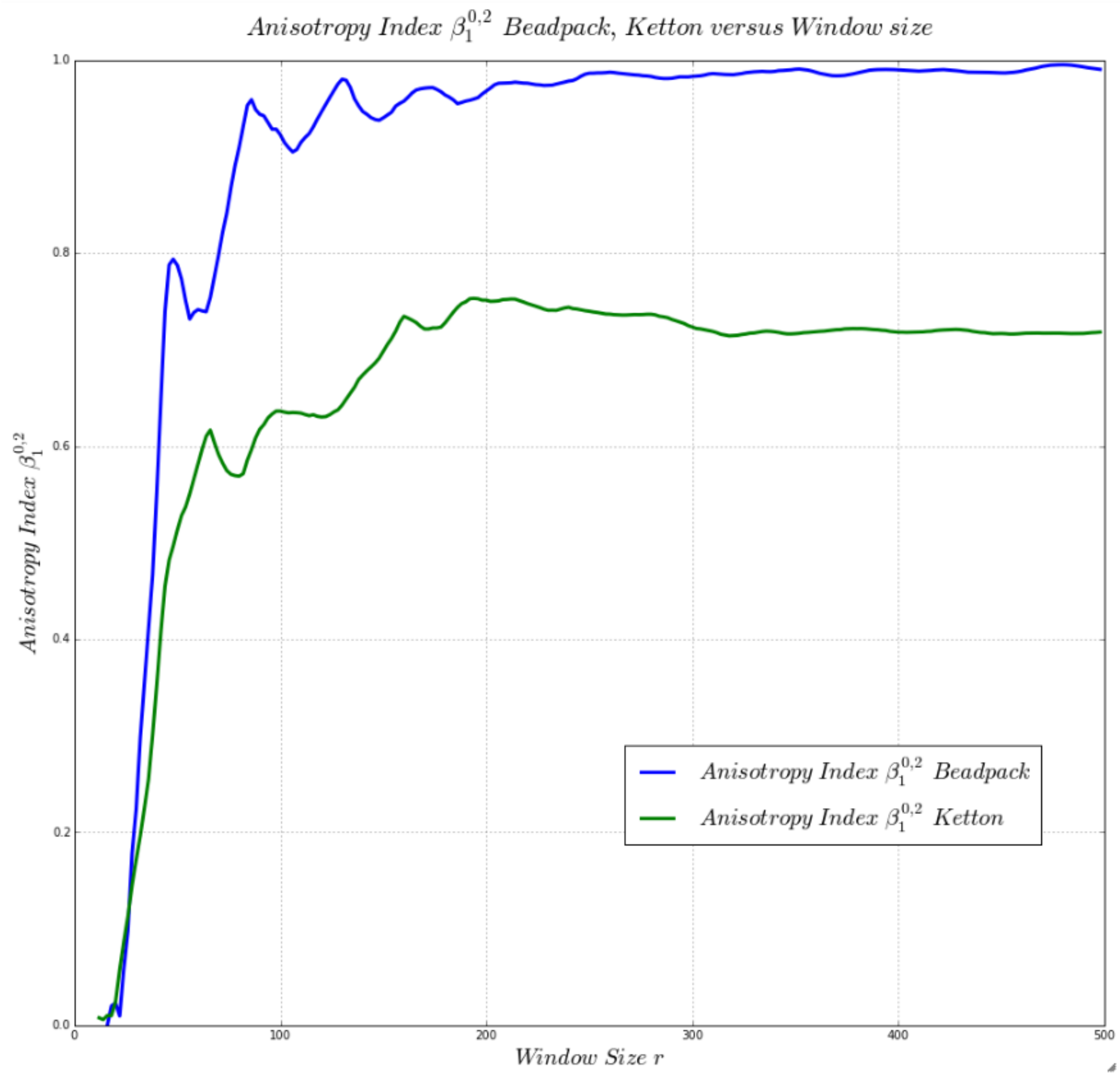
$REV = 400\ voxels$

Imperial College London

Comparison Beadpack/Ketton

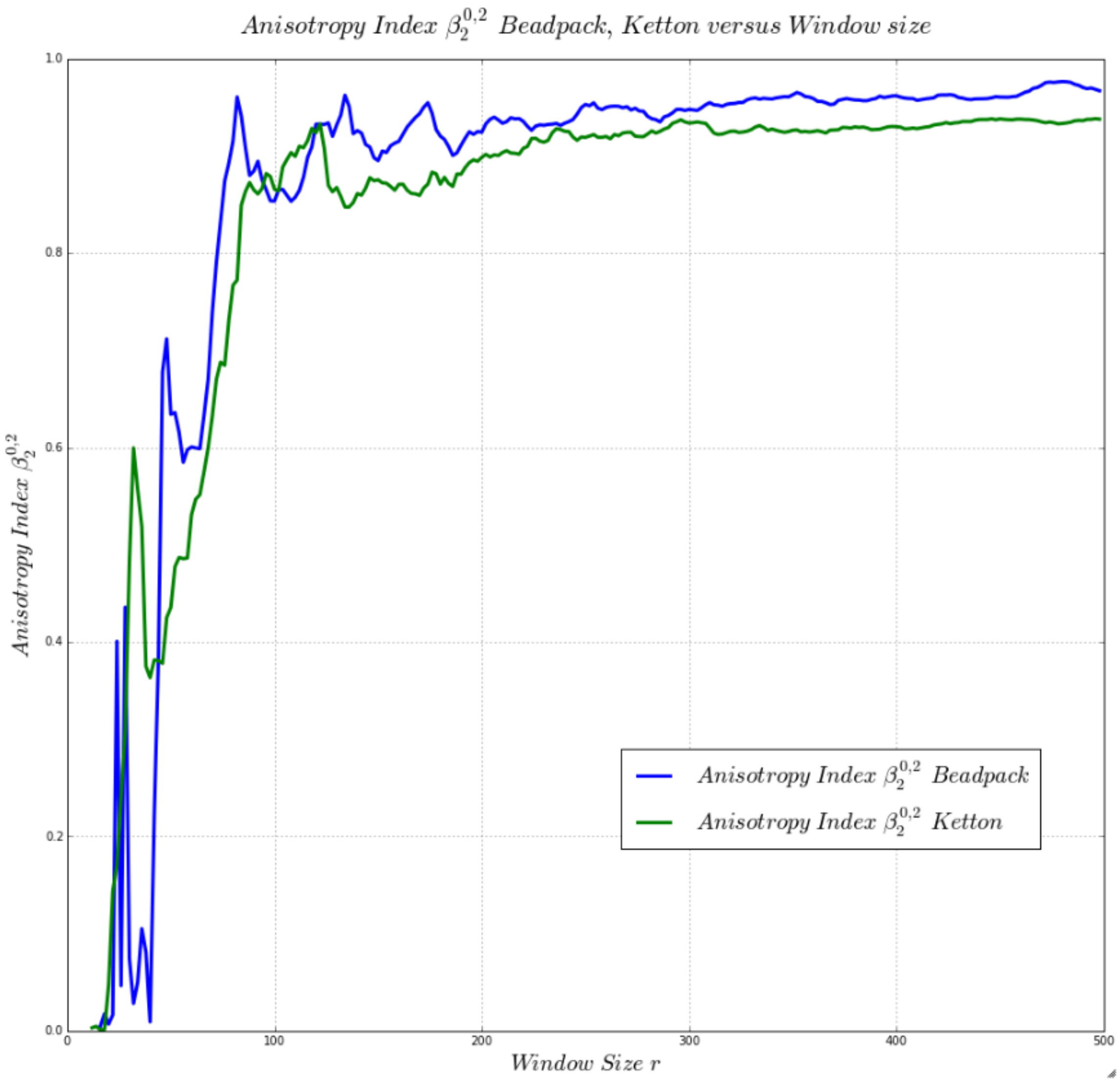
Comparison Ketton and Beadpack Results

Comparison Beadpack/Ketton – Beta 102

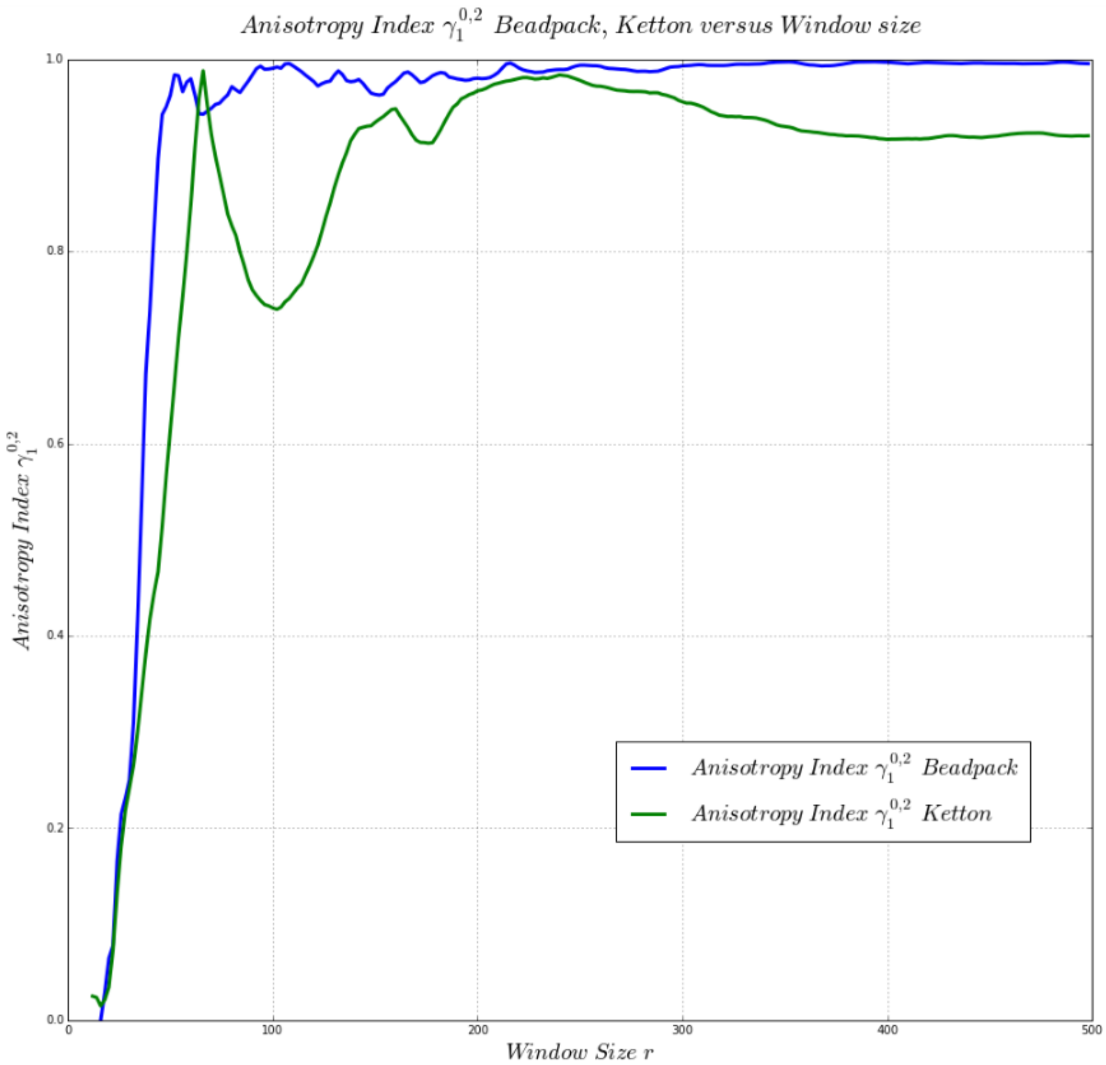


Imperial College London

Comparison Beadpack/Ketton – Beta 202



Comparison Beadpack/Ketton – Gamma 102



Comparison Beadpack Ketton – Gamma 202