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Statistical Characterisation of Porous Media at the Pore Scale

“Scoping it out”

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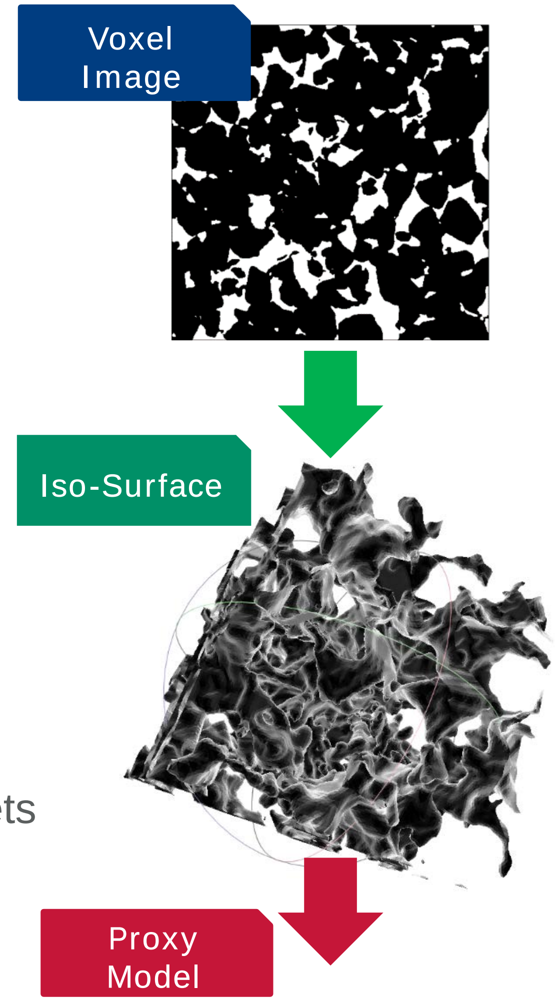
Presentation Outline

- **Review Workflow**
- **Approach**
- **Setup**
- **Results**
- **Next Steps**

Review Workflow

- Critical literature:
  - pore scale imaging
  - image morphology
  - random materials
- Collection and screening of available datasets.
- Development of workflow to facilitate computation of tensorial Minkowski functionals based on voxel Micro-CT images:
  - Extraction of iso-surfaces based on image segmentation
  - Computation of tensorial functionals on triangulated surface
- Computation of tensorial functionals on available datasets
- Evaluation of tensorial Minkowski functionals as proxies for material properties and as classifiers of pore scale structures of porous media



$$\bar{\bar{k}} = a\bar{\bar{W}}_1^{0,2}$$

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Approach

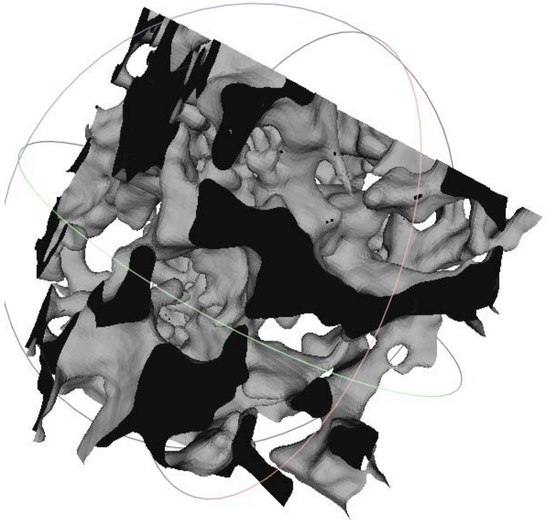
- Start with simple image – Dr. Bijeljic: Ketton most resemblance to bead pack
- Use available software for Minkowski Tensor calculation:
  - Karambola: University of Erlangen, Link
- Create Input file writer for Karambola software:
  - Mesh Vertices, Faces to .poly file
  - Use simple sphere mesh to test functionality
- Extract Isosurface of pore space from 3D image
- Select largest connected pore space: Isolated vugs disregarded for now
- Output Isosurface to Karambola software
- Run Karambola
- Read back results
- Plot anisotropy measures:
  - Eigenvalues of Tensors W102 and W202 (translation invariant)

Setup

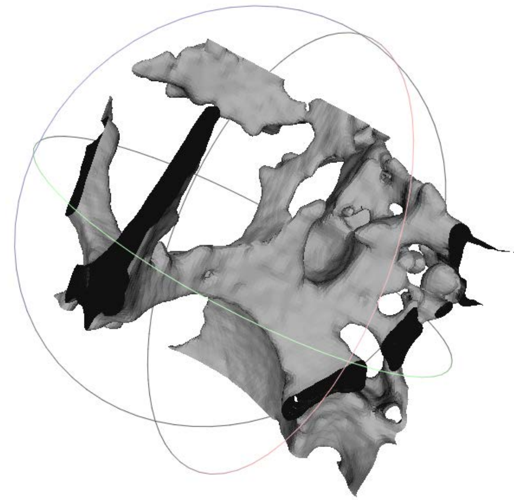
- Three Central Parts:
  - Karambola -> Calculate Tensors
  - Jupyter Notebook (former ipython notebook) -> File Handling, Results
  - ImageJ -> Create input image
- ImageJ:
  - Convert Image from raw to tif, easier to read and smaller file
- Jupyter notebook:
  - Load image
  - Apply 3D Gaussian filter to image (scikit-image)
  - Subdivide image into nx by ny by nz subvolumes (100x100x100 => 64 regions)
  - Extract Isosurface at levelset and output to .off file and write to Karambola
  - Find largest connected surface (most triangles)
  - Run Karambola (Ubuntu machine)
  - Read results for each subvolume (Pandas read_csv and custom class)
  - Do this for all images (Ketton, Berea, Bentheimer, Estaillades)
  - Plot Results

Results 1: Subvolume Isosurfaces @ 0.8 level (100^3)

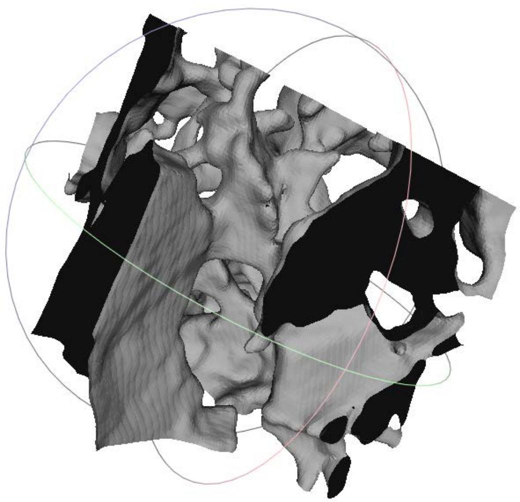
Ketton



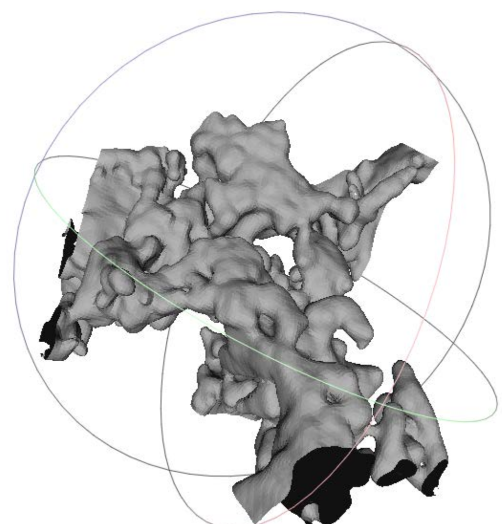
Berea



Bentheimer



Estaillades



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Results 2: Tensors Invariant to translation

$(W_1^{0,2})_{ij}$	$\frac{1}{3}\int_{\partial K} \mathbf{n}_i \mathbf{n}_j \, \mathrm{d}A$	$\frac{1}{3}\sum_{T\in\mathcal{F}_2} \lvert T\rvert \, (\mathbf{n}_T^2)_{ij}$
$(W_2^{0,2})_{ij}$	$\frac{1}{3}\int_{\partial K} G_2 \, \mathbf{n}_i \mathbf{n}_j \, \mathrm{d}A$	$\frac{1}{24}\sum_{\mathbf{e}\in\mathcal{F}_1} \lvert\mathbf{e}\rvert \, ((\alpha_\mathbf{e} + \sin\alpha_\mathbf{e})(\ddot{\mathbf{n}}_\mathbf{e}^2)_{ij} + (\alpha_\mathbf{e} - \sin\alpha_\mathbf{e})(\dot{\mathbf{n}}_\mathbf{e}^2)_{ij})$

A rank-2 tensor is defined to be *isotropic* if and only if it is proportional to the unit tensor Q, i.e. its eigenvalues are all equal. Deviations from isotropy are measured by the anisotropy index $\beta_\nu^{r,s}$, which is the ratio of extremal eigenvalues of the tensor $W_\nu^{r,s}$. For example, let ξ_μ ($|\xi_1| \leq |\xi_2| \leq |\xi_3|$) be the eigenvalues of $W_1^{0,2}$, then the anisotropy index is

$$\beta_1^{0,2} := \left|\frac{\xi_1}{\xi_3}\right| \in [0,1]. \tag{41}$$

By definition, this quantity is dimensionless, continuous and rotation invariant. The value of 1 indicates perfect isotropy, and smaller values indicate anisotropy. For anisotropic bodies, it is sometimes also useful to consider $\gamma_1^{0,2} = |\xi_2/\xi_3|$.

From Schröder 2009

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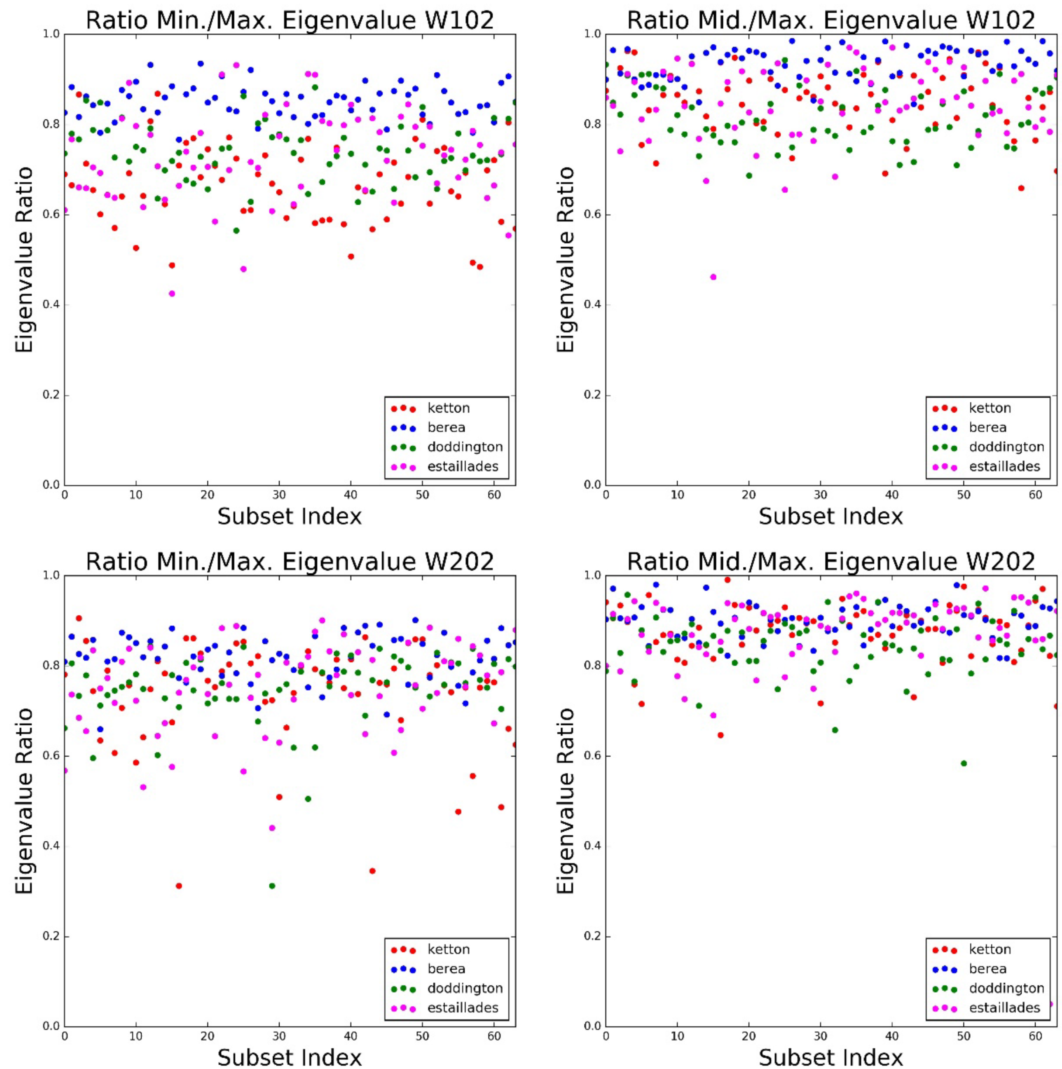
Results 3: Raw Data for each subvolume Beta, Gamma

- Most data between 0.6 and 1.0
- Berea has highest values
- Ketton seems lowest
- Some seperation seen between ketton berea and doddington
- Estaillades greatest spread
- Plot not very indicative



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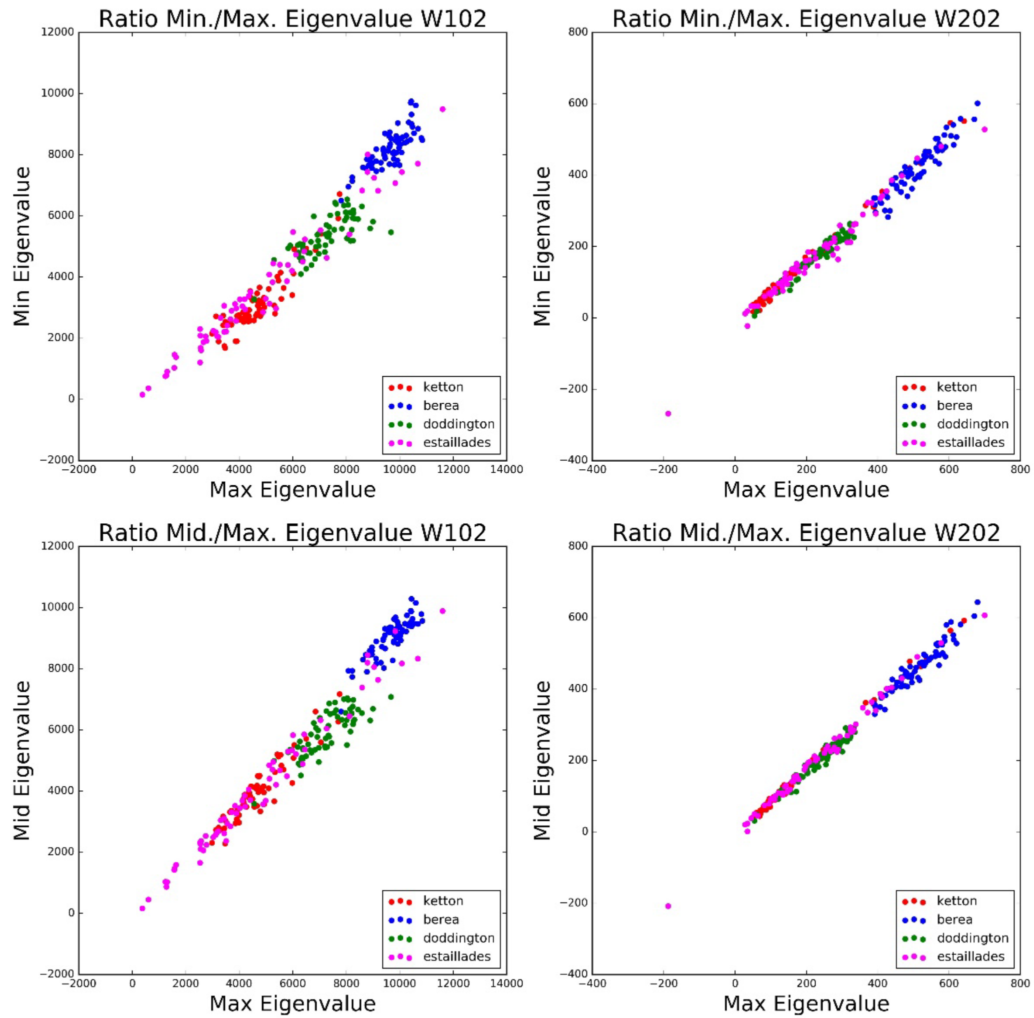
Results 4: Crossplot Min/Mid vs. Max Eigenvalue

- Separation between rock samples is much more pronounced
- Estaillades again large spread
- Separation due to magnitude of eigenvalues, is this an intrinsic property or dependent on each sample volume (to-check!)



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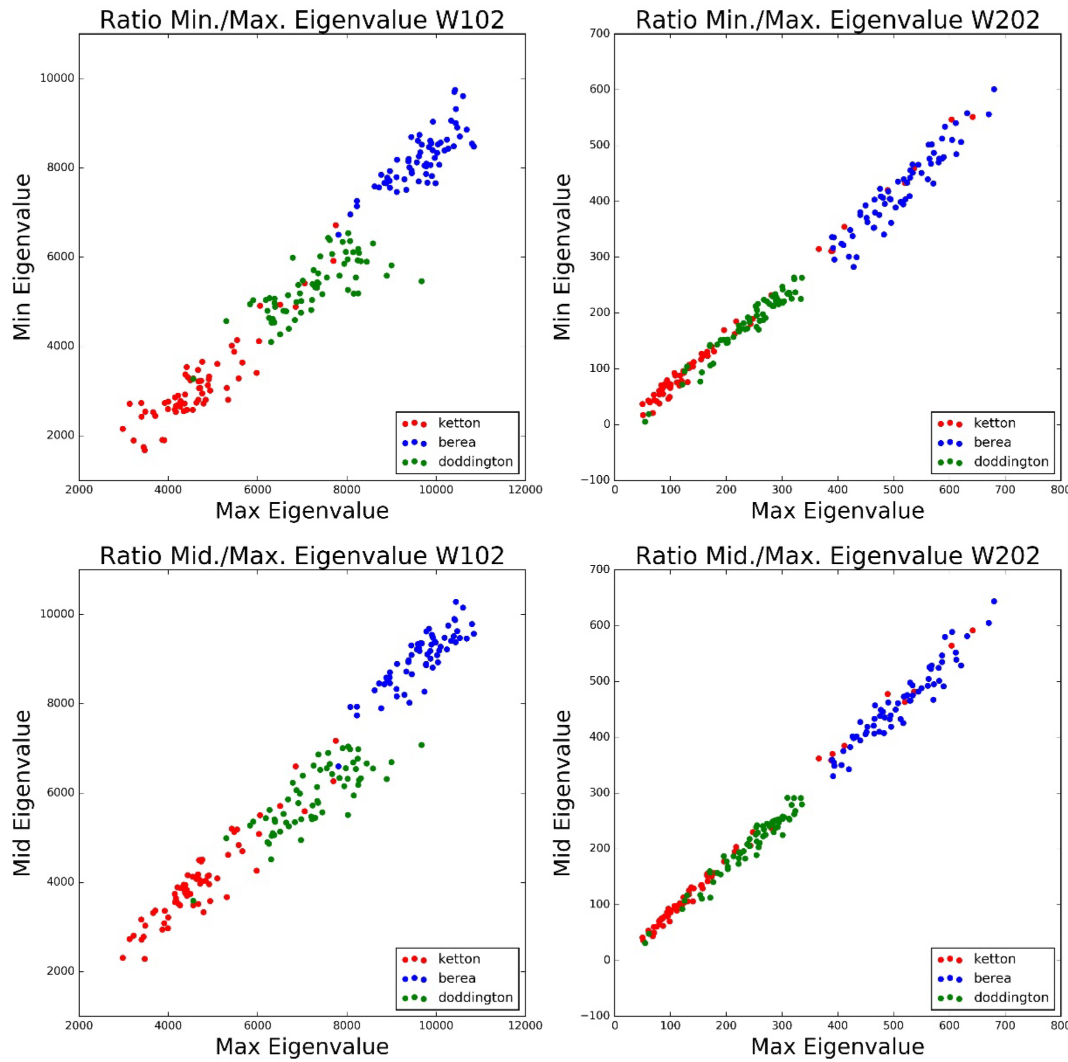
Results 5: Crossplot Min/Mid vs. Max Eigenvalue (w/o estailades)

- Clear seperation of samples
- But may be false positive due to requirement of normalisation
- Not yet clear based on literature
- Things to check next
- But nevertheless interesting as each image same voxel counts
- Worth investigating!

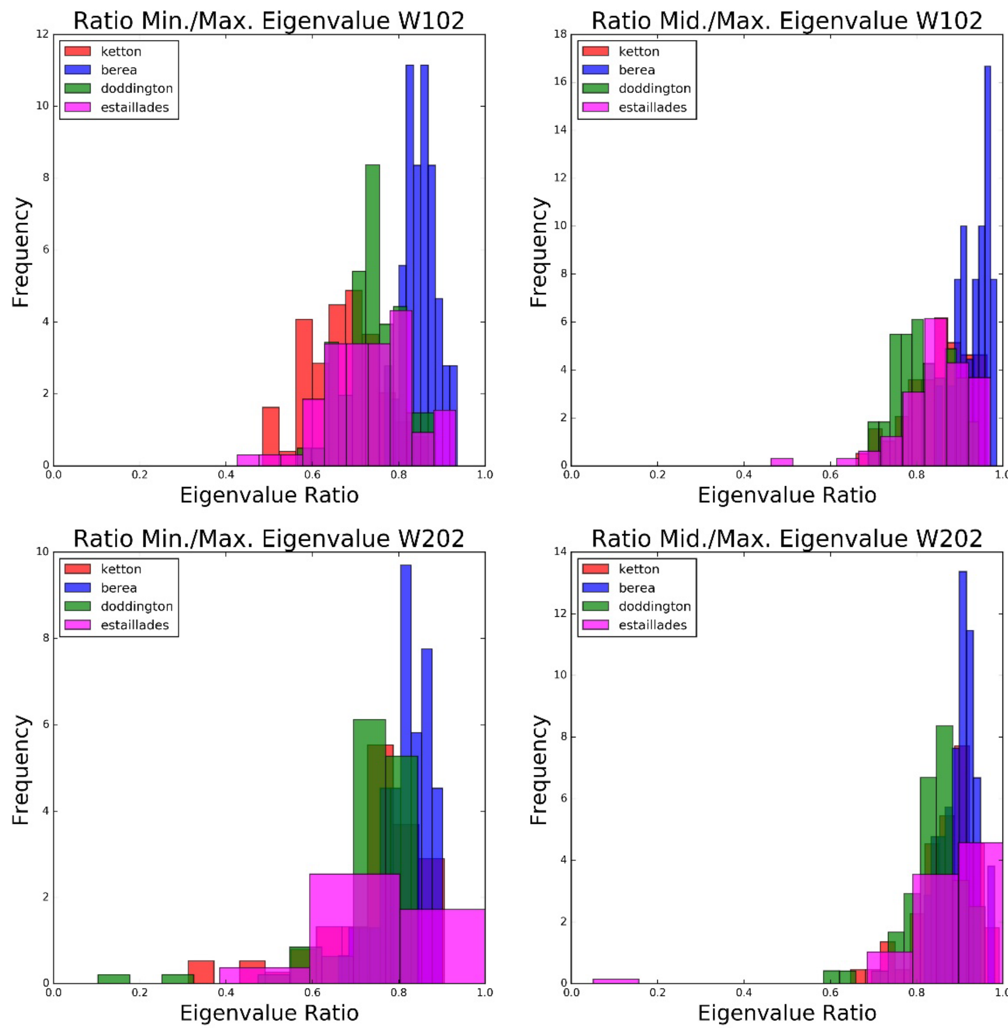


Results 3: Histograms of Anisotropy measures

- Histograms of Anisotropy measures
- Show distinct families of values
- According to literature:

  anisotropy measures are

  dimensionless -> actual behavior
- Can Identify spread in estaillades
- Very focused peak in berea



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Next Steps

- Dependency of results on segmentation level
- Check for false positiveness, are results supposed to be normalized?
    - Will check previous applications and compare treatment
- Extract isosurface using Avizo
- Compare Boolean model (can be generated in python or rhino 3D)
- Run larger and smaller subvolume runs
    - Currently limited to memory of laptop
    - 100^3 largest laptop can handle
- Eigenvector plots exist but no good way of visualizing main directions yet found
    - Possibly use stereonets and mean poles