Progress towards designing stellarator non-resonant divertors

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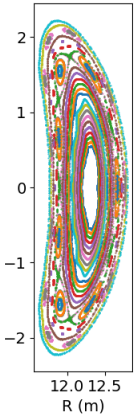
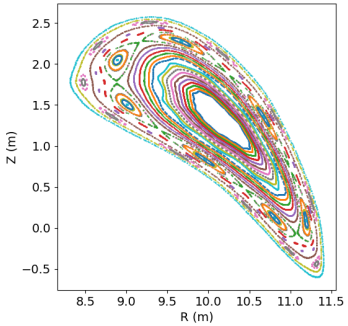
Accurate field information at finite pressure is still a challenge

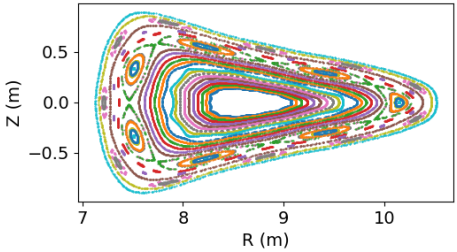
- Basic idea: combine VMEC (or other) solution for plasma with Biot-Savart from coils
- Challenge 1: VMEC includes a numerical surface current on the boundary which causes violation of $\nabla \cdot \mathbf{B} = 0$
- Solutions that involve virtual casing principles tend to struggle with handling the surface current
- Temp solution: Use BMW code to calculate magnetic potential from plasma and from coils, then calculate field with $\mathbf{B} = \nabla \times \mathbf{A}$
- Issue: solution is bad near the core, tends to overestimate island size and stochasticity internal to the plasma

Flux surfaces from Wistell-D using BMW



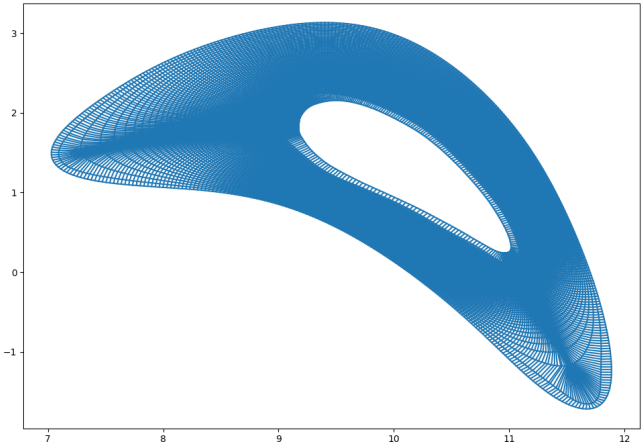


- Large islands appear in outer half of the plasma, may not be realistic
- Core region is known to be incorrect
- Plasma/edge boundary is ”smooth” without surface currents



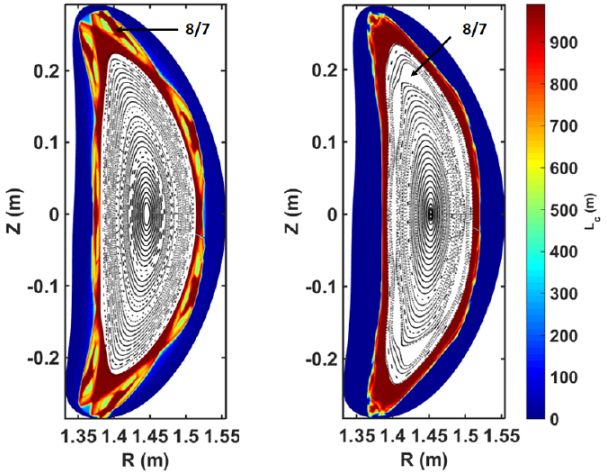
Difficult magnetics create challenges for EMC3 grid making

- Inner surfaces must be good flux surfaces
- Outer surfaces must extend past LCFS



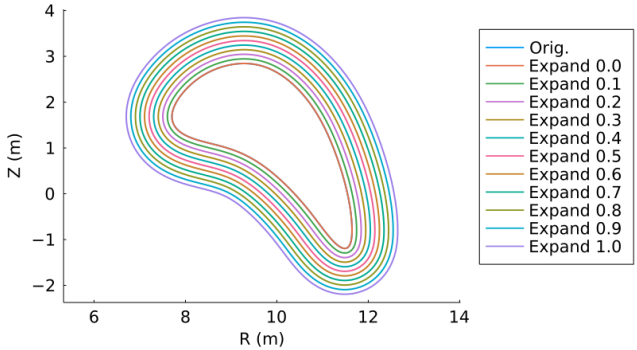
How to extend surfaces properly?

- Stellarator boundaries tend to be surrounded by complicated topological regions including closed surfaces, islands, cantori
- Mapping cantori, for example, is difficult
- Ideally, extend grid only in regions of longer connection lengths



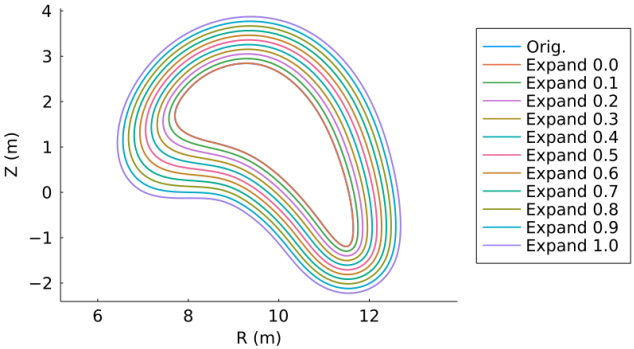
Simplest approach - 2D uniform

- For each point on the 2D surface, calculate the local projection of $d\vec{\psi}/ds$ in the R, Z plane
- Step out a uniform distance, Δ from the boundary



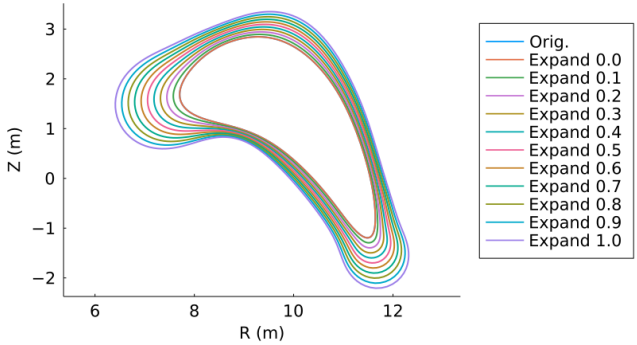
One Step better - 3D uniform

- For each point on the 2D surface (s_0, θ, ζ), calculate the angle $\hat{\zeta}$ such that $(s_0, \theta, \hat{\zeta})$ + $\Delta\hat{n}$ lies on the ζ plane
- Here $\hat{n}$ = $(d\vec{\psi}/ds)/(|d\vec{\psi}/ds)|$
- This ensures the expanded surface is always Δ away from the original surface



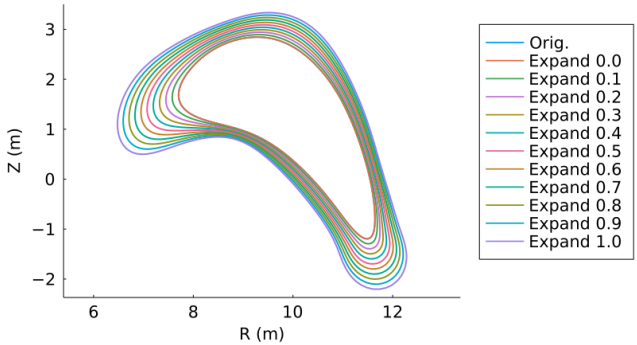
Non-uniform expansion - 2D

- Similar to the 2D uniform expansion, although attempt to account for the natural variation
- Idea: use local magnitude of $|d\vec{\psi}/ds|$ as a scaling factor to expand more in regions where the flux surfaces have larger expansions inside the LCFS
- Use a local value of $\Delta^* = \Delta \left(\frac{|d\vec{\psi}_{\min}/ds|}{|d\vec{\psi}/ds|} \right)^{\alpha}$ from the boundary



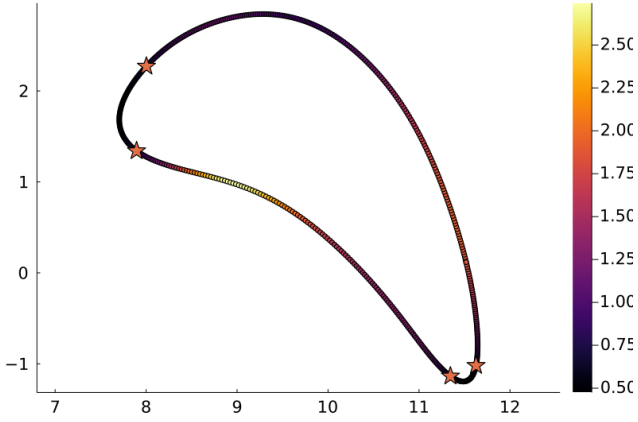
Non-uniform expansion - 3D

- Expand as in the uniform case but instead of a constant Δ solve for $\hat{\zeta}$ using $\Delta * (\hat{\zeta})$
- Close to the boundary this should mimic the most realistic expansion. Farther from the boundary it is less reliable



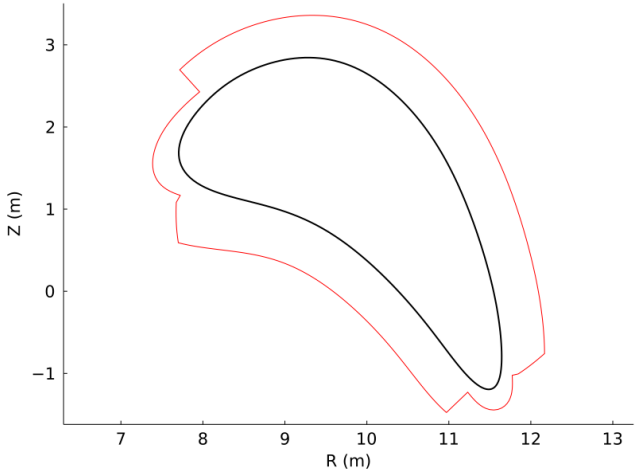
$|d\vec{\psi}/ds|$ can also be a proxy for where to position divertor plates

- In general divertors will likely want to be placed in regions of high flux expansion
  - Longer ballistic distance between wall and plasma
  - Larger shaping gives more opportunities to provide baffling and trap neutral gases
- Idea: set threshold value for $|d\vec{\psi}/ds|$ that can be used for possible divertor positions

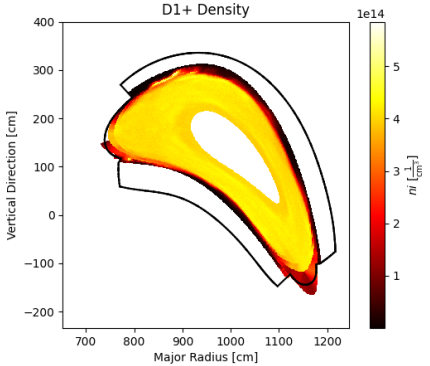


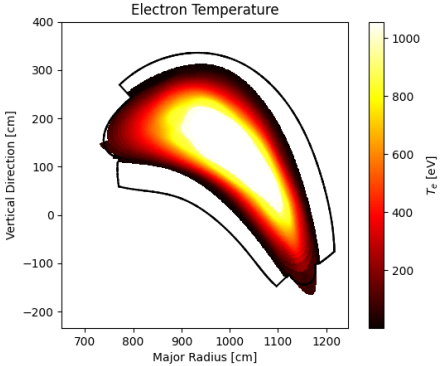
Constructing candidate walls

- When $|d\vec{\psi}/ds|$ below threshold value, put divertor at non-uniform expansion with Δ = 0.25 cm
- On other places put non-plasma facing surface wall at uniform expansion of 50 cm
- Use interpolated values to connect to get a smooth surface (only important for FLARE implementation)



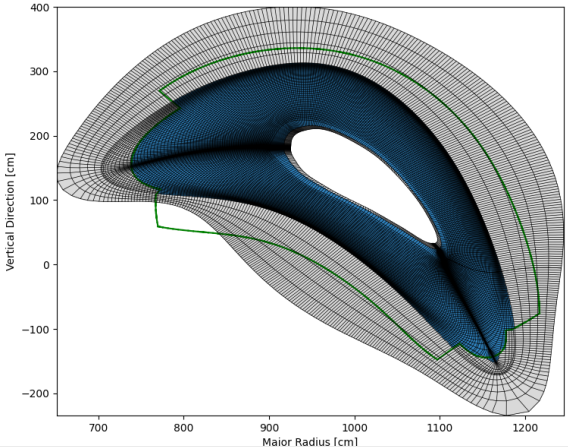
Grid based on divertor implemented, but has issues





Needs better resolution at edge. Local hotspots exist on edges currently, need to adjust α or threshold for divertor

Improved grid underway



Next steps

- Set up fast analysis of strike point with field line following for rapid analysis of divertors
- Either figure out some bugs in flare or generate own routine for making base grid
- Long term: better workflow to go from VMEC + coils to edge grid. Would like alternative to BMW
- Long term: Get mathematicians to help us figure out how to quickly generate estimates for Cantori surfaces