Optimizing stellarators for better equilibria through the addition of physics objectives to DESC

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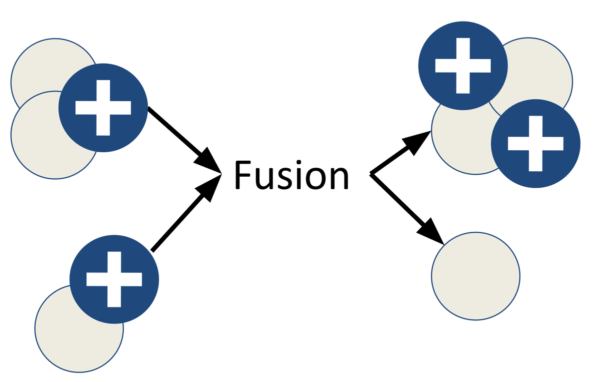
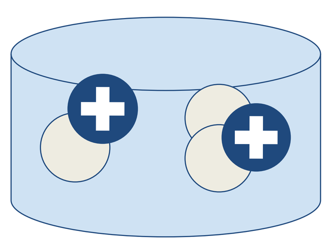
Introduction

What is fusion?



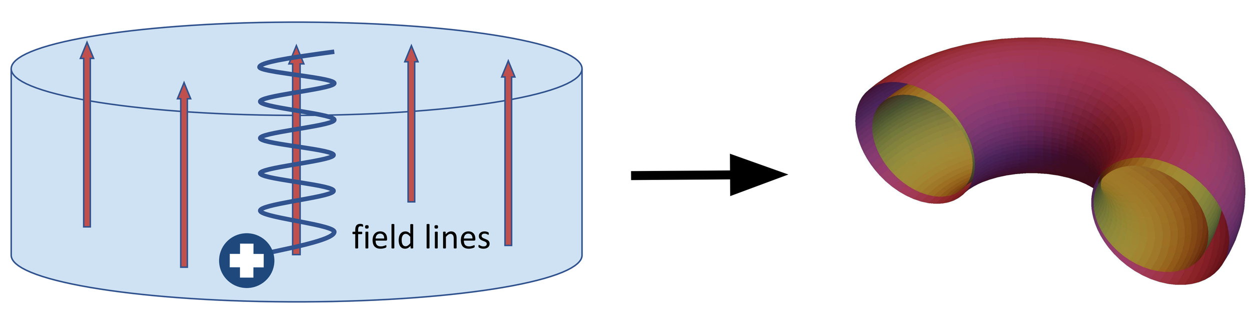
- Clean, cheap, abundant energy
- Nuclear strong force keeps protons together
- Helium + neutron output has less mass than the Tritium + Deuterium input
  - special relativity relates energy to the effective mass
- Lost mass is converted into kinetic energy of the neutron and heat

Stellarators: Motivation



- Place hydrogen isotopes (the fuel) in a container
- Heating increases random motion of particles
- At high temperatures, random collisions result in fusion

A challenge: Confinement



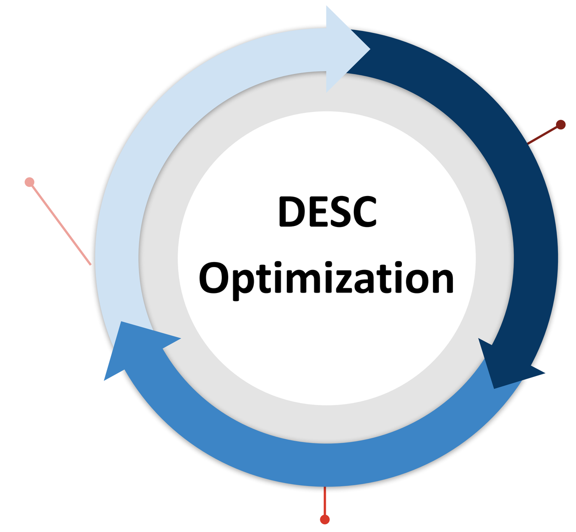
- Only magnetic fields can confine hot plasma
- Charged particles gyrate around magnetic field lines
- Confines motion of particles to a tube around the magnetic field lines

Stellarator codes

- The general 3D equilibrium problem has no known analytical solution
- Need to find equilibrium numerically
- Used to design device geometry and magnetic field configuration

DESC Stellarator Code

Equilibrium Solve
Reduce force balance residuals



Check
Is the optimization criteria satisfied?

yes → Done

Perturbation
Toward optimization objective

1 More accurate
- Pseudo-spectral equilibrium solver
- Avoids coordinate singularity that would give bad accuracy near axis
- Perturbation and continuation methods

2 Faster
- Stellarator design space is big
- DESC enables discovery of more optimal equilibria in larger search spaces
- Automatic differentiation

3 Modern code
- Works with GPUs, giving orders of magnitude speed increases
- Python
- Open source

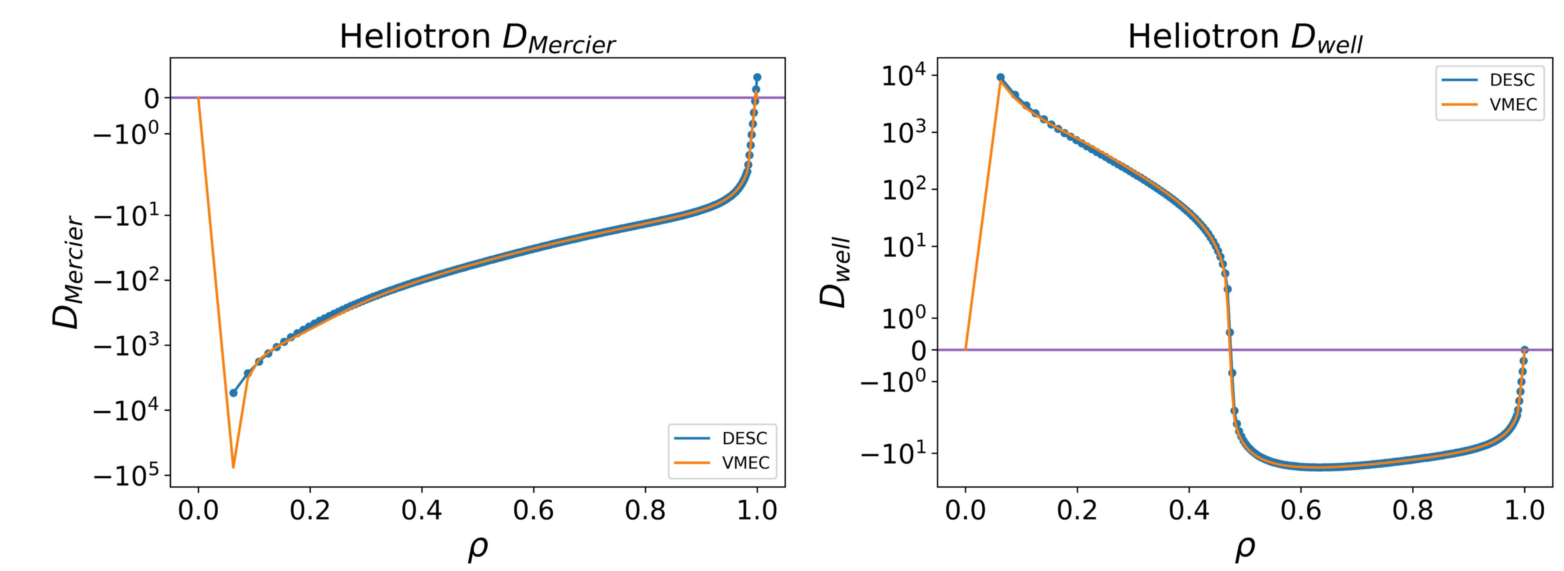
Optimization Objectives

Plasma Stability

- Plasma is stable (unstable) if perturbation will dampen (grow) with time
- Many types of instabilities exist which challenge the goal of profitable fusion

Mercier Stability Criterion

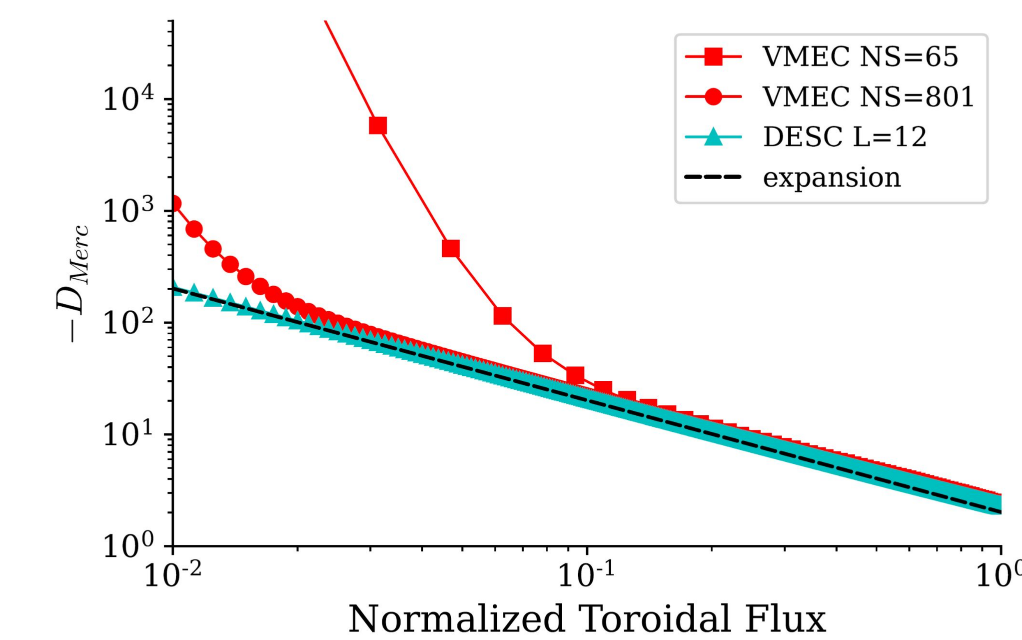
- Fast proxy for MHD stability
- Useful figure of merit for stellarator optimization and design



DESC resolves the **magnetic axis with more accuracy** than legacy codes

- Valuable for studying stability in equilibria

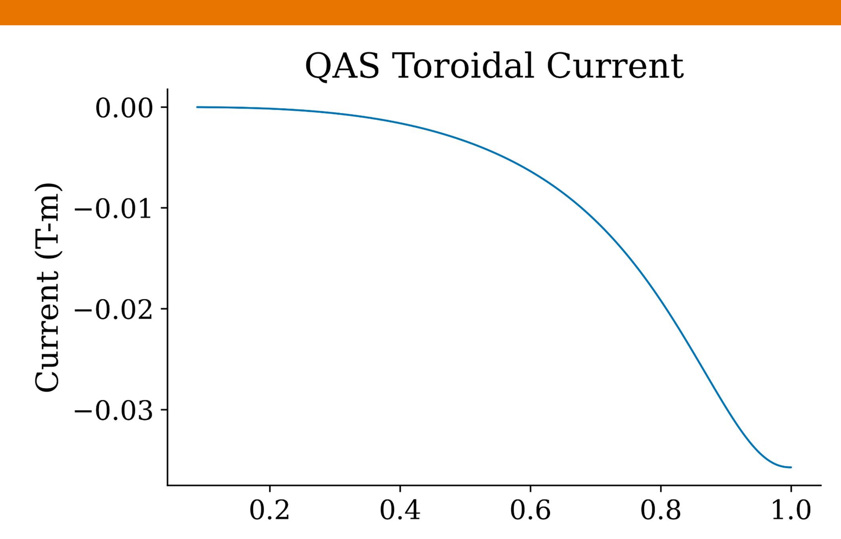
quasi-helically symmetric configuration with an aspect ratio of ~ 8

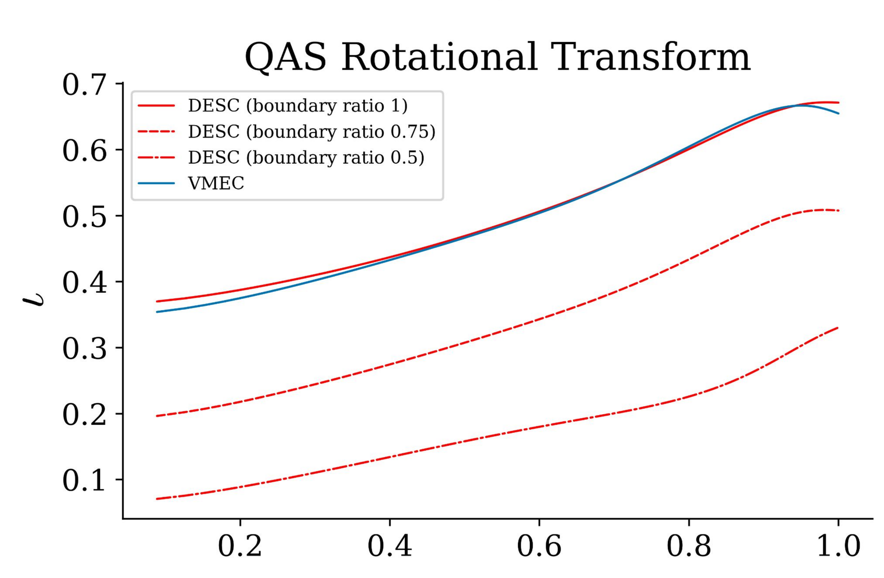


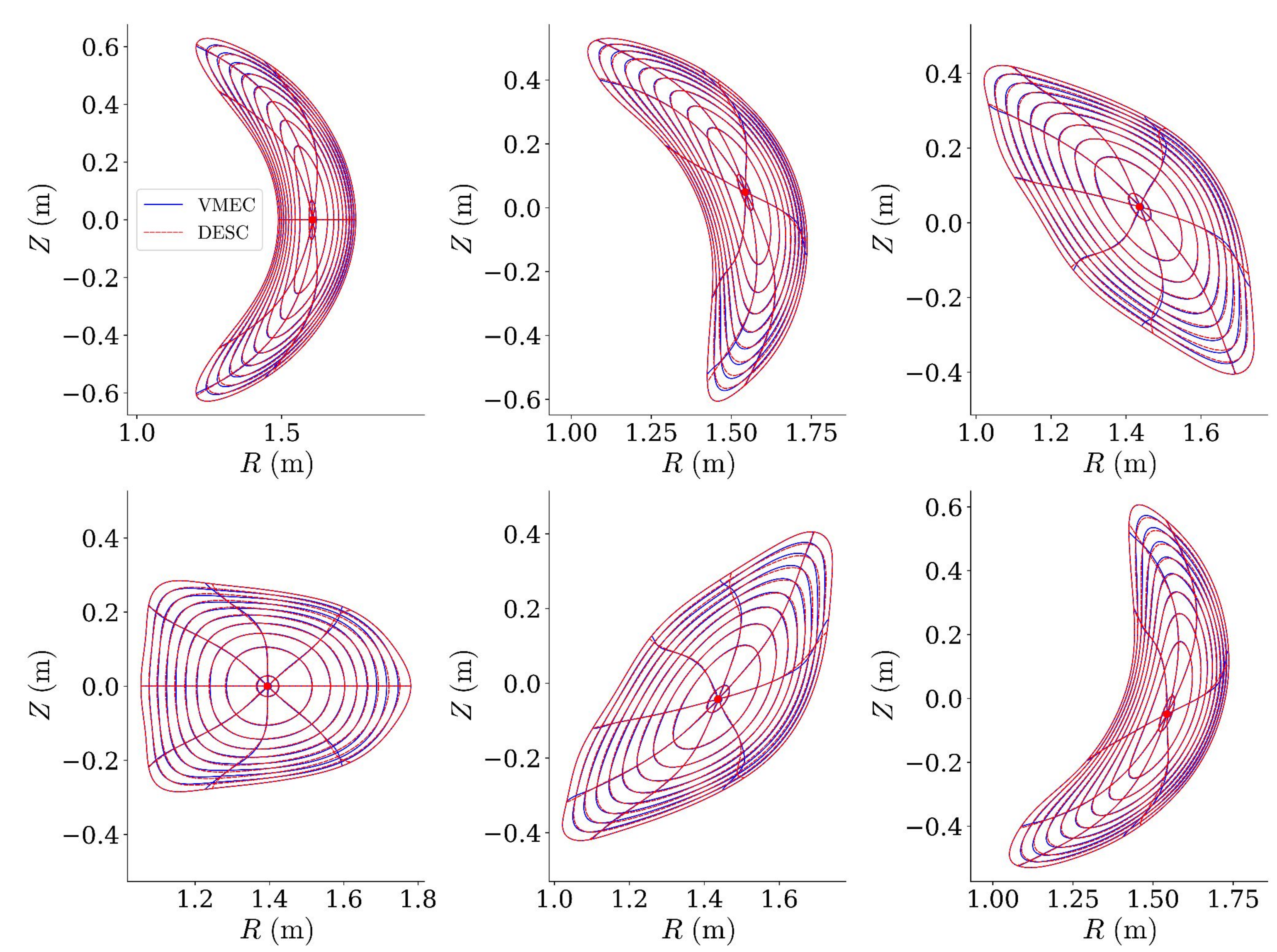
Equilibrium Solutions with fixed Toroidal Current

Rotational transform

- Key component in stellarator design required for confinement
- DESC can now solve equilibrium given a toroidal current profile input instead of the rotational transform
- An example equilibrium solution is shown to the right







Acknowledgements

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This work was supported by the U.S. Department of Energy under contract numbers DE-AC02-09CH11466, DE-SC0022005 and Field Work Proposal No. 1019, as well as Princeton OURSIP and the Horton Elmer Fund.