THEA ENERGY

Reinventing the Stellarator

D. A. Gates

44th FPA meeting

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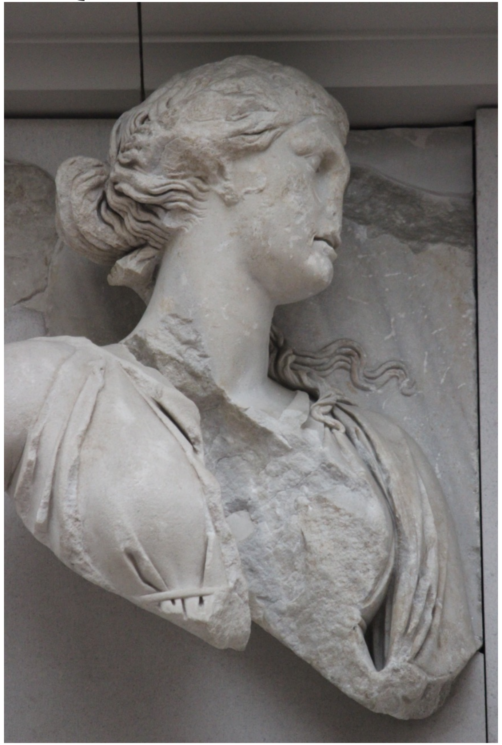
Creating a limitless source of zero emission energy for a sustainable future

We have a new name: Thea Energy (www.thea.energy)

Formerly Princeton Stellarators, Inc.

- Thea (also Theia) was the titan goddess of divine light and vision
- She was the daughter of Gaia, the Earth Goddess
- She gave birth to Eos (the Dawn), Helios (the sun), and Selena (the moon)
  - Our first machine will be called Eos
  - Our Fusion Pilot Plant will be called Helios



Bust of Thea from the Pergamon Altar
Wikimedia:
19 April 2014, 17:04
Author:
Miguel Hermoso Cuesta

Stellarator coil design methods

- Modern stellarator coil design based on the method of P. Merkel (Nucl. Fusion 1987 **27** 867)
- Define your optimized equilibrium with plasma parameters of interest (improved neoclassical confinement, MHD stability, etc.)
- Create a uniformly offset surface called the winding surface
- Find the distribution of currents on the winding surface that minimizes the normal field on the plasma boundary (B·n = 0 on a flux surface)
- Use the resulting current potential contours to define coils
- Iterate the resulting free boundary equilibrium to improve the plasma properties consistent with real coils

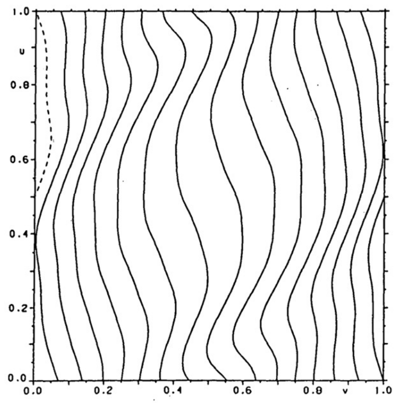


FIG. 4. Surface current lines of Helias vacuum field in the (u, v) plane. Number of Fourier harmonics $\hat{\Phi}_{mn}: m \leqslant 4, |n| \leqslant 4$.

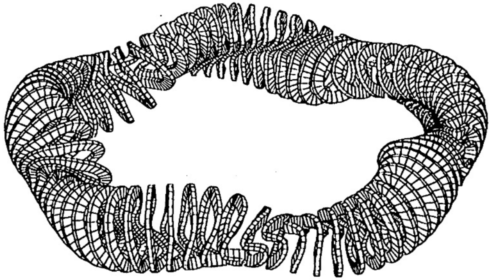


FIG. 5. Modular coils for Helias stellarator. Number of coils per period: $N_c = 15$. Aspect ratio of coil configuration: $A = 6.5$.

Simplified coils for stellarators: the Thea method

- Concept: **2 step optimization procedure**

1. Optimize “toroidal” encircling coils
2. Minimize remaining normal field with an array of “dipole coils”

- Coil Requirements:

1. All coils will be planar and convex enabling winding under tension – normal winding machine for simple production
2. Large gaps between encircling coils enabling sector maintenance
3. Small number of unique coils enabling economies of scale

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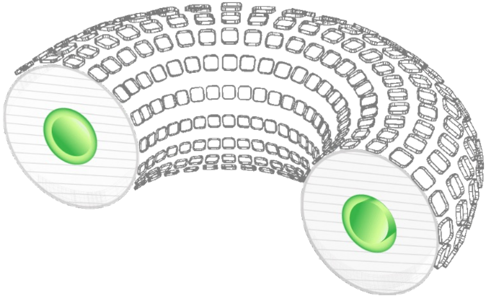
A practical approach to commercializing fusion

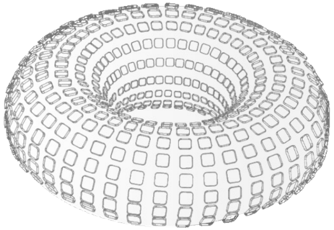
Dynamic System Control

We can optimize machine parameters and dynamically change operating points in real-time



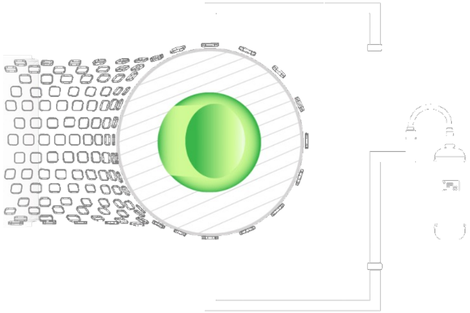
Simplified Commercial System Maintenance and Operation

Geometry enables sector maintenance with access and large sector removal better than even tokamak design



Capable of Near-Term Commercial Operation

D-D fusion for the production of tritium and other radioisotopes with steady state operation



Big Coil Optimization results

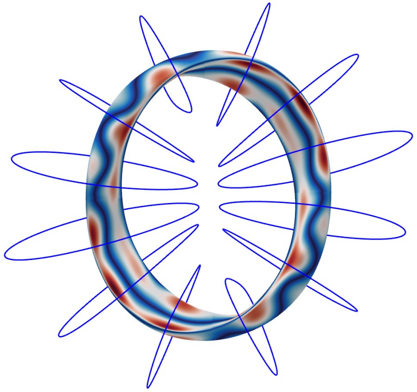
Results for 2 field period, finite beta equilibrium with self-consistent bootstrap current

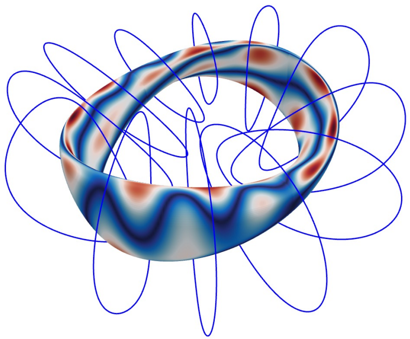
- R = 2.7 m
- R/a = 6
- B_0 = 6 T

Optimization of big coils reduces maximum normal field error below 1 Tesla

- Mean error ~3x lower
- Largest errors are localized
- No coils with regions of high curvature

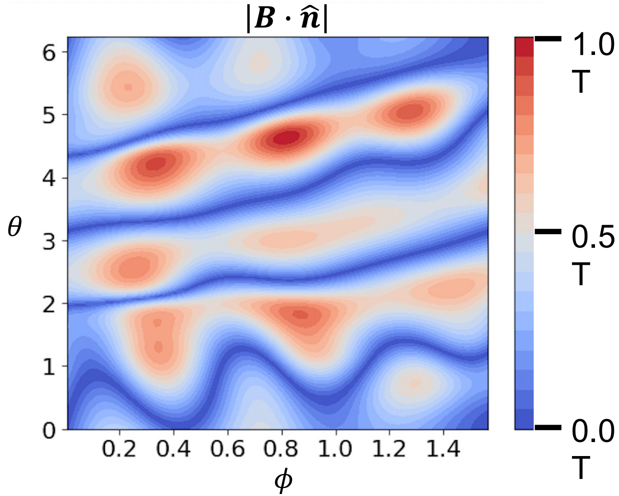
Big coil optimization significantly reduces demand on small coils





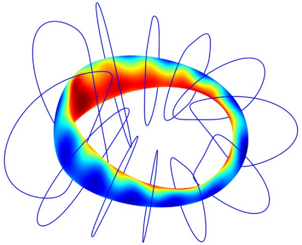
Residual normal field from *only* big coils

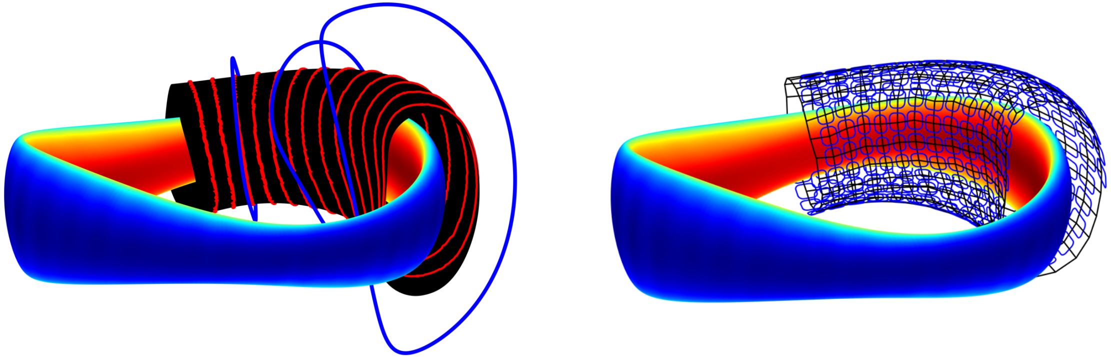
Max $|\boldsymbol{B} \cdot \hat{\boldsymbol{n}}|$ = 0.98 T
Mean $|\boldsymbol{B} \cdot \hat{\boldsymbol{n}}|$ = 0.35 T



Planar Stellarator Coils Designed for Sector Maintenance

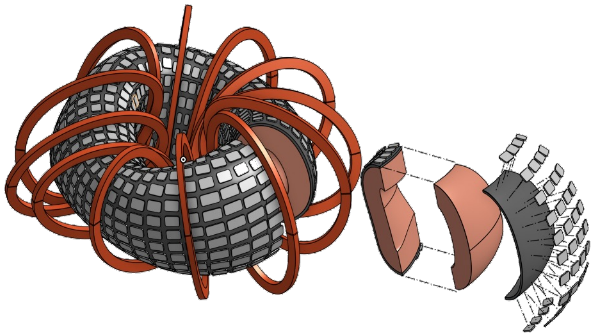
- Planar encircling coils (TF) provide most of the confining magnetic field
- A “winding surface” is used to locate the smaller planar coils within a coil array
- Coil columns (poloidal rings) are defined by the encircling coils
- Large toroidal sectors of the stellarator’s radial assembly can be extracted between the encircling coils





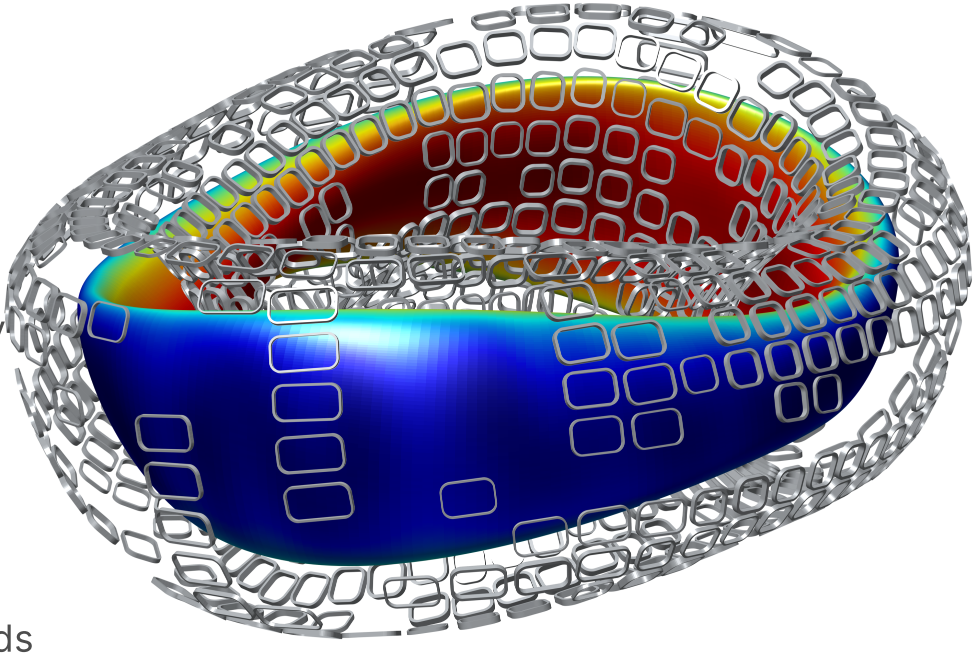
A winding surface is segmented by interpolating encircling coil planes

SECTOR MAINTENANCE CAPABILITY



All Planar Coil Systems Generate Highly Symmetric Fields

- Coil system is split into subgroups each with their own power supplies
  for active control
  - Plasma startup from 0 beta to operating point
  - Precise magnetic topology control
  - In-situ configurability
- Radial access defined by gaps in the coil array
  - Large tangential NBI access
  - Normal and tangential diagnostic ports
  - Cryogenic and electric feedthroughs
- Optimization constraints ensure engineering feasibility
  - Adequate spacing for blankets and shields
  - HTS critical current



Thea Energy will design, construct, and operate a large-scale neutron source stellarator, Eos

Eos is the only first-generation fusion system prototypical of a power plant

Not contingent on further scientific breakthroughs

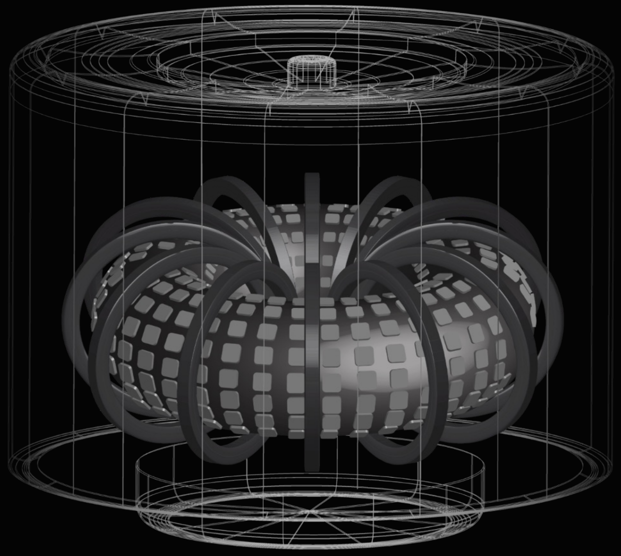
Timeline similar to largest proof-of-concept prototypes

Thermal generation on accelerated trajectory

Capable of generating near-term revenue

Commercial operations supporting fleet adoption:

- Tritium production
- Fusion power plant technology development
- Medical isotope production (e.g. Shine)
- Breakdown of long-lived radioactive waste



Near-term commercialization - not a moonshot

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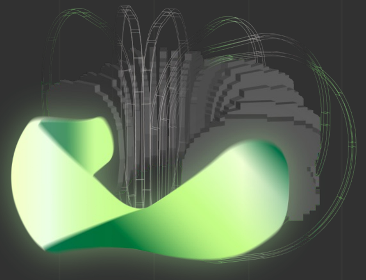
The path to commercial fusion

2020 COMPLETED

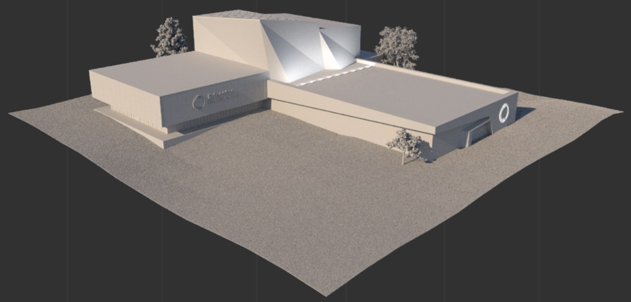
2023 PRE-CONCEPTUAL DESIGN COMPLETED

2030

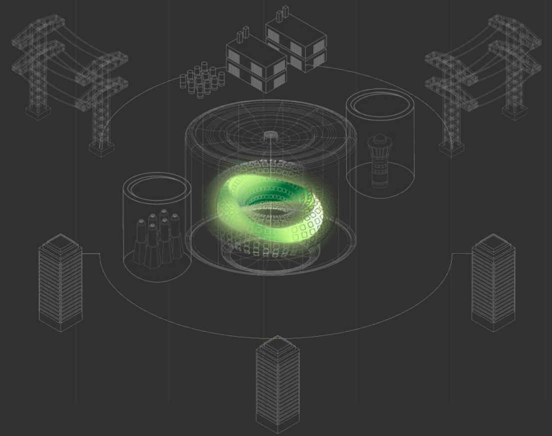
ARPA-E Project



EOS Neutron Source Stellarator



Helios Power Plant



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