The Helically Symmetric Experiment: a stellarator for studying transport, edge physics, and developing fusion diagnostics

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Helically Symmetric eXperiment

The HSX Stellarator

Vision

HSX supports both private and public fusion endeavors to close the remaining gaps on the path to delivering clean, limitless fusion energy.

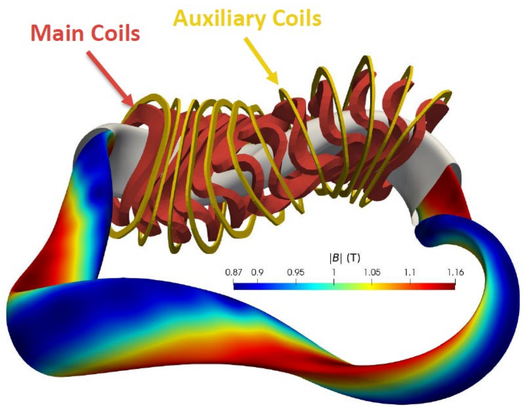
Mission

The HSX stellarator experiment drives progress in stellarator physics, pioneers technologies essential for future fusion power plants, and prepares a highly trained workforce.

Operational parameters

- World's first quasi-helically symmetric stellarator
- Major/minor radius: 1.2 m/12 cm
- Modular coil design
  - 48 non-planar coils
  - 48 planar auxiliary coils
- Possible to vary degree of symmetry
- Te = 1 keV - 3 keV
- ne= 2 x 10^{18} - 8 x 10^{18} m^{-3}
- Pulse length 50 ms
- Main field: 0.5, 1.0, 1.25* Tesla

*Pending upgrade completion



Heating and Fueling Systems

Current ECRH system

- 28 GHz Varian gyrotron delivering 100 kW
- O1-mode heating at 1 T
  - 20% - 30% absorption
- X2-mode heating at 0.5 T
  - 50% - 60% absorption

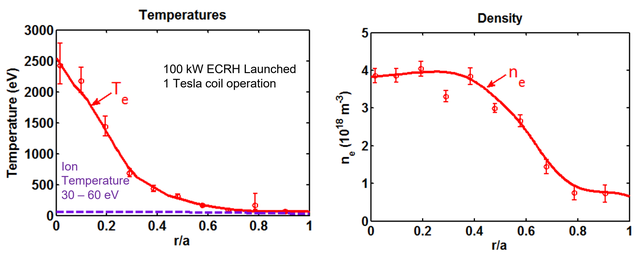
Upgraded ECRH system

(under construction)

- 70 GHz CPI gyrotron
- Donated by IPP Greifswald
- 500 kW of power for 3 s (aim: 200 kW, 0.1 s)
- X2-mode heating at 1.25 T
  - >90% absorption

Gas Puffing

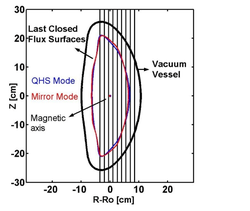
- Pulse-width modulated control of Piezo-electric valves
- Super-sonic gas injector deployed

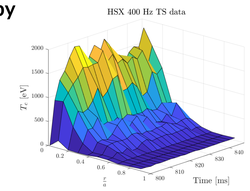


Advanced Diagnostics

Operational Diagnostics

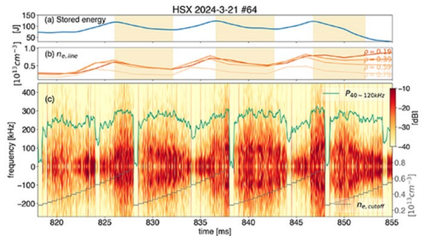
- **mm-wave interferometry** (Deng RSI 2010)
  - 7 channels, 1 MHz sampling
- **Thomson Scattering** (Goodman RSI 2022)
  - 10 spatial channels
  - 400 Hz sampling
  - Multi-bandpass polychrometer filters
- **Charge Exchange Recombination Spectroscopy**
  - Ion temperature, flow, density
  - 30 kV well-focused, monoenergetic DNB

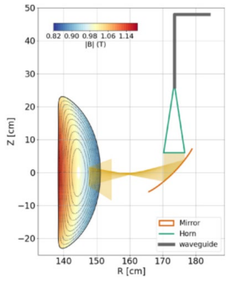




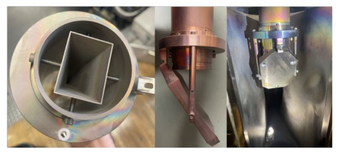
Turbulence Diagnostics

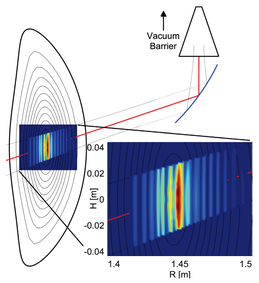
- **Reflectometry**
  - Monostatic antenna
  - Sampling rate up to 10 MS/s
  - Upgrade to Doppler reflectometer

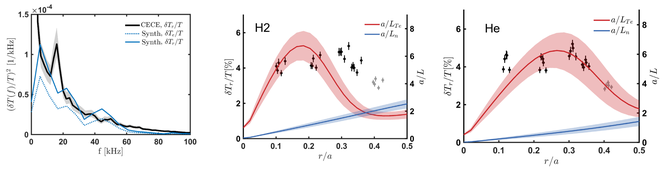




- **Electron Cyclotron Emission (ECE)**
  - 200 kHz 8 Channel radiometer
  - Different mixers available for 0.5, 1.0, and 1.25 T
  - Additional 16 channel radiometer operated as a correlation radiometer





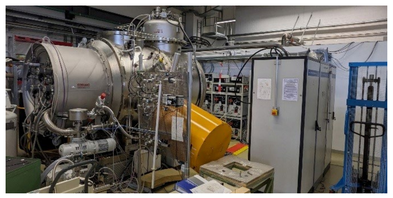


- **Deployment of hardened Hall sensors to map magnetic field** (collaborative work with Stanford University)

Neutral Beam Injector Development

60 kV, 150 kW RUDI-X NBI system donated by IPP Garching

- Originally designed as diagnostic beam for W7-X
- High density operation allows target plasma

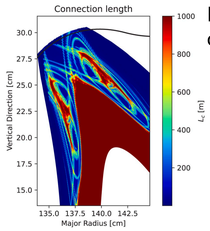


Benefits of NBI operation:

- Fast-ion studies
- Momentum source
- Higher ion temperature

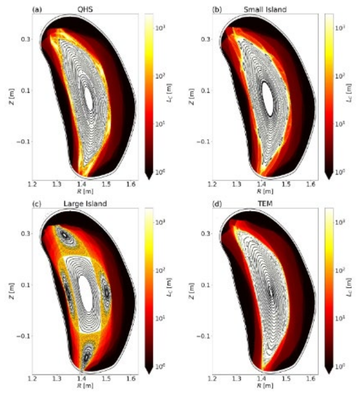
Davydenko *et al.* AIP Conf. Proc. 1771, 030025 (2016)

Edge Physics

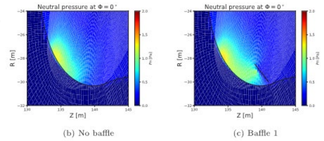


HSX edge is characteristic of a non-resonant divertor

Modeling of the strikeline behavior across a number of magnetic configurations with and without large islands shows that the divertor exhibits resilient behavior



Boeyaert *et al Nuclear Materials and Energy* **42 (2025)**



A baffle design study indicates conditions for increasing neutral compression

K A Garcia et al, *Plasma Phys. Control. Fusion* **67 (2025)**

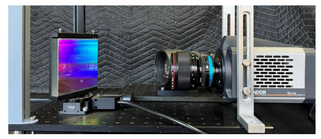
Visible Impurity Spectroscopy

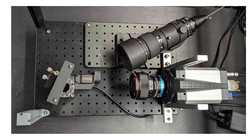
A series of custom spectrometer designs provide a spectral survey across the visible range

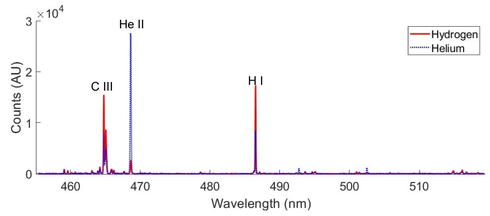
Plasma impurity species are identified to aid in determining sources of plasma material interaction and determine effectiveness of strike line conditioning

A fast camera (10 kHz) provides detailed imaging of the strikeline

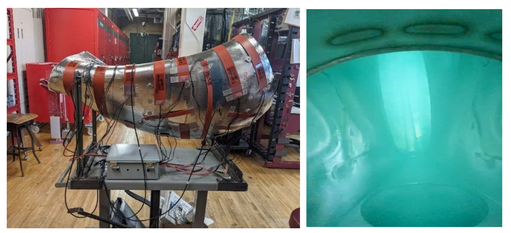
AXUV diode arrays provide estimate of radiated power







Wall Conditioning



Vacuum conditions are established using heated walls (60 C) and helium and/or argon glow discharge cleaning

An impurity powder dropper on loan from PPPL can source boron into glow discharge plasmas or with 2.45 GHz heating (in development)

Collaboration

Research on HSX relies on:

- A highly collaborative and well-trained team of engineers, scientists, and students.
- Strong partnerships between experimental and theoretical research groups across the U.S. and around the world (*e.g.* gyrokinetic turbulence, ECH deposition, and neoclassical transport modeling)
- HSX offers an excellent testbed for fusion technology development and actively welcomes collaborations with both the private and public sectors.

INFUSE FY 2026 Workshop, Oak Ridge, TN, November 6, 2025

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