# DIII-D Topical Science/Technology Area on Heating and Current Drive

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**On behalf of the H&CD Topical Area**

Presented at Plasma-Interacting Technology Research Strategic Planning Meeting

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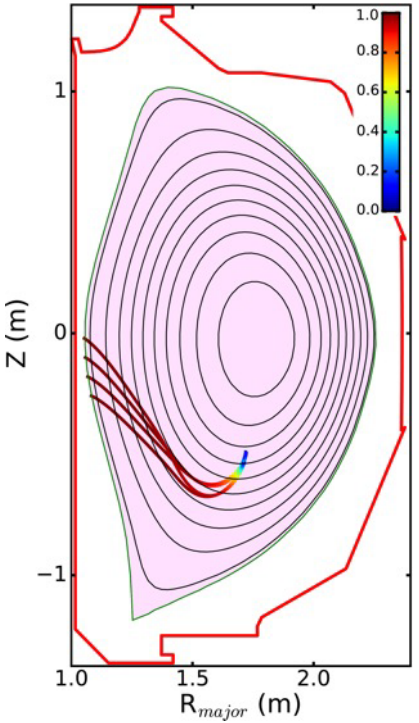


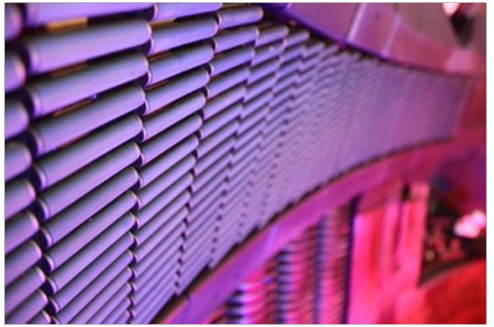

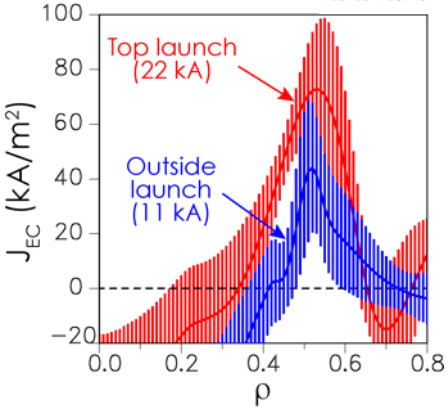


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# DIII-D topical area on heating and current drive

- **Our group is concerned with the development and application of actuators to manipulate distribution functions of plasma constituents:**
  - Heating of electrons and ions (width of velocity distributions as function of position
  - Rotation (shift of ion distribution function)
  - Current drive (toroidal asymmetry of electron distribution function)
  - In principle, higher-order moments ("phase space engineering")
- **This is done with neutral beams and various rf systems**
  - NBI and the rf systems are at different levels of maturity

# NBI is the everyday workhorse of H&CD systems at DIII-D

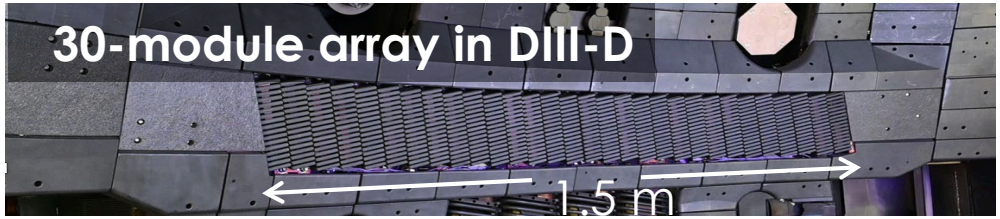
- **NBI used since the beginning of Doublet III (late 1970s)**
  - Up to 20 MW of deuterium NBI available for use on DIII-D
    - One quarter of the power can be changed from co- to counter
    - Half of the power is available for off-axis deposition with tilted sources
    - One quarter can be changed from on-axis to off-axis
    - Beams can run in hydrogen at lower power levels
    - Beam energy can be adjusted, perveance
    - Controllable in several ways in real time

# 110 GHz ECH/ECCD is the next-most mature system

- This system has been under development since mid-1990s (followed the 2 MW 60 GHz system that was used on DIII and in early DIII-D)
- High-water mark has been 6 gyrotrons simultaneously for ~3.5 MW coupled power; gyrotrons can operate up to 5 sec pulses
- System employs outside launchers above the midplane, steerable in both poloidal and toroidal angles
- Poloidal steering can be controlled in real time, though this capability is seldom used in recent years
- Top launch studied 2019-2023, possibly again after 2024

# “Helicon” system operational from 2021 with a single large klystron at 476 MHz

- **“Helicon” = Fast Wave in lower hybrid range of frequencies (extension of familiar ICRF fast wave to higher frequencies)**
- **Also known as “whistler” or HHFW in other contexts**
- **Antenna invented here by Charles Moeller is a form of traveling-wave antenna known as the “comb-line”**
  - Present DIII-D comb-line has 30 elements (see photo)
  - Naturally “load-resilient”
  - Power absorption via direct electron absorption (Landau damping)
- **Full power of source (1.2 MW) has been applied to the antenna for short pulses in 2023**
- **Experiments have utilized up to about half of that power coupled to the plasma (~0.65 MW)**



# High-field-side Lower Hybrid Current Drive system being installed right now for operation in 2024

- **HFS LHCD is a twist on long-established technique using quasi-electrostatic slow waves in the Lower Hybrid Range of Frequencies**
- **System designed and constructed by MIT uses 8 x 0.25 MW klystrons at 4.6 GHz and innovative waveguide array launcher constructed with additive manufacturing technology in a special copper alloy**
- **Aim is to establish 1 MW of coupled power to DIII-D plasmas in a directive spectrum to drive non-inductive currents at high efficiency**

One of 8 toroidally arrayed modules with 4 rows of apertures



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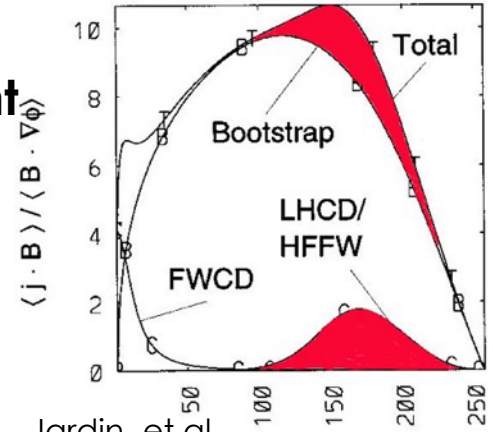
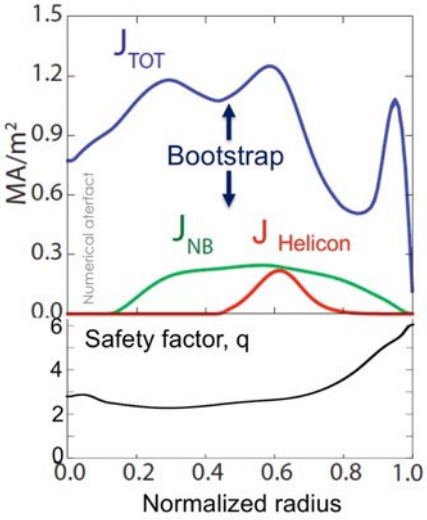
# Efficient mid-radius non-inductive current drive is needed for AT reactors

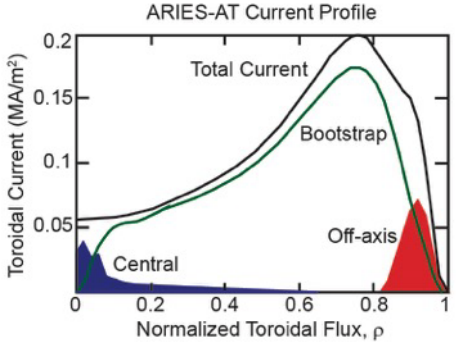
- **Steady-state advanced tokamak reactors require non-inductive current drive in the mid-radius region**
  - Understood for ~25 years or more
- **DIII-D is evaluating three methods for off-axis rf current drive:**
  - Nearly-vertical launch ECCD (experiments started 2019 - )
  - Helicon current drive (experiments started 2021 - )
  - HFS-launch LHCD (to be tested 2024 - )




Jardin, et al., Fusion Eng. Des. **1997** (ARIES-RS)




Buttery, et al., Nucl. Fusion **2021** (CAT)




Najmabadi et al., Fus. Eng. Des. **2006** (ARIES-AT)



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# H&CD proposes two thrusts, each in support of a Milestone

- **For 2024, approved Milestone for HFS LHCD system commissioning, due September 2024**
  - Propose continuation of "H&CD Readiness Thrust" of previous years
  - Of dedicated time, HFS LHCD will need only a portion of the shot, so helicon work is proposed for part of the remaining discharge
  - S. Wukitch will address this
- **For 2025, proposed Milestone for helicon physics would motivate another Thrust to maximize the likelihood of delivering the proposed results**
  - B. Van Compernolle will address this