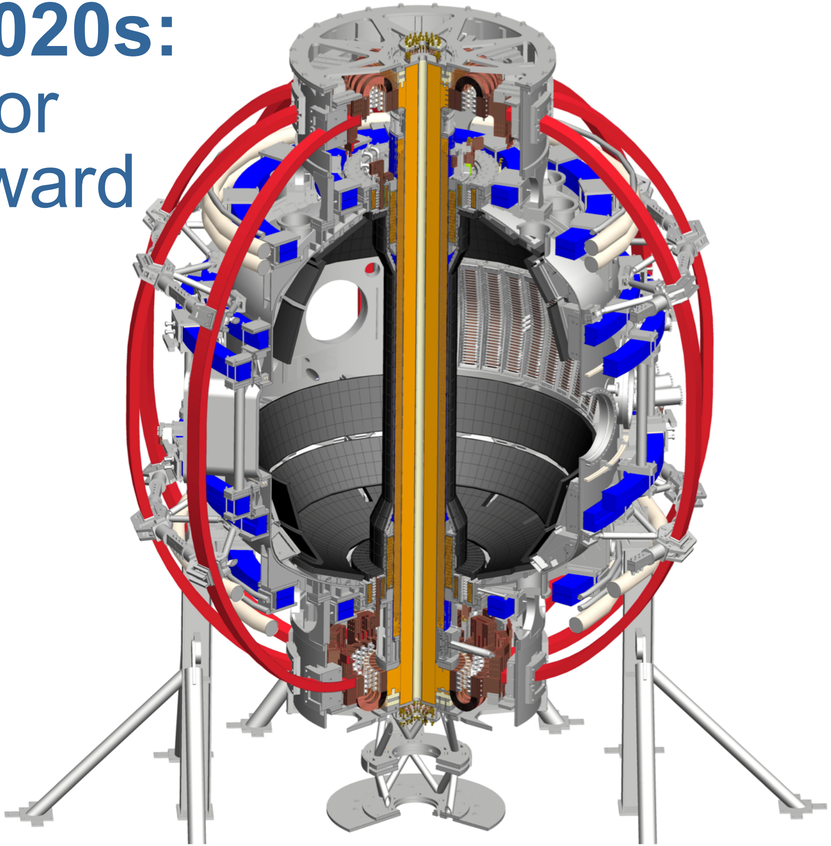
NSTX-U

NSTX-U is sponsored by the
U.S. Department of Energy Office of Science
Fusion Energy Sciences

The NSTX-U Facility in the 2020s:
Advancing the Physics Basis for Configuration Optimization Toward a Compact Fusion Pilot Plant



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DRY RUN: July 15, 2019

Joint Community Planning
Workshop for MFE and FM&T

Madison, WI

July 22-26, 2019

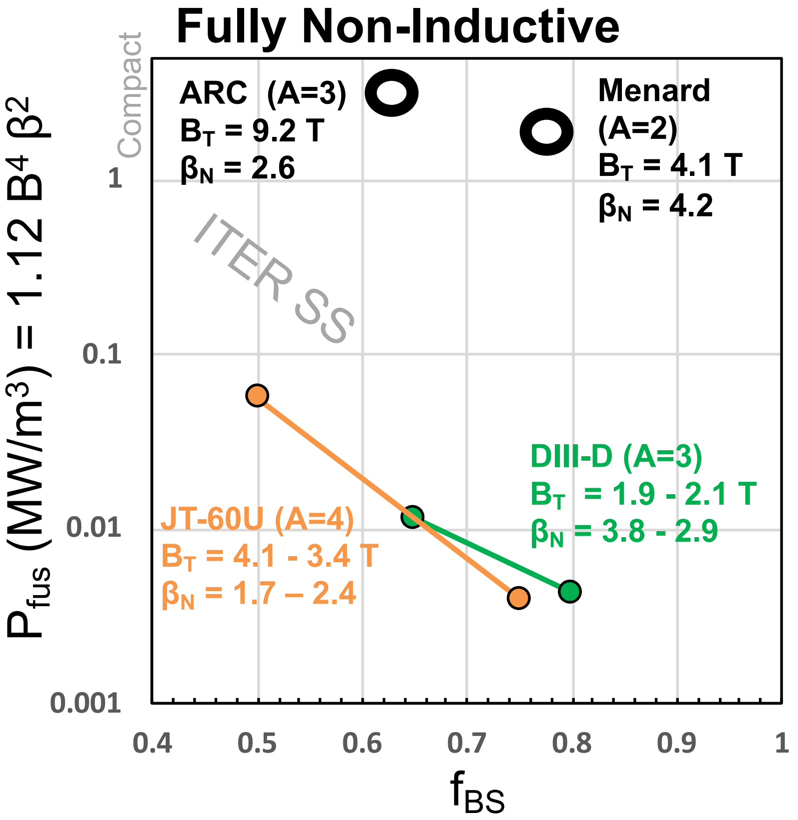
The NAS recommendations elevate the importance of the NSTX-U mission

- NSTX-U will provide critical data required to optimize the configuration of next-step compact devices
- NSTX-U will evaluate integrated operations with liquid metal PFCs that would enable compact fusion systems
- NSTX-U will provide unique regimes for studying burning plasma physics and accelerating predictive capabilities

Compact Fusion PP designs require physics basis for non-inductive regimes at high f_{BS}

- Tokamak HTS CFPP concepts: f_{BS} > 60% and $H_{98y,2}$ = 1.5 – 2
  - Fully non-inductive without impurity and He ash accumulation
  - Scenario must be compatible with divertor solution for heat flux

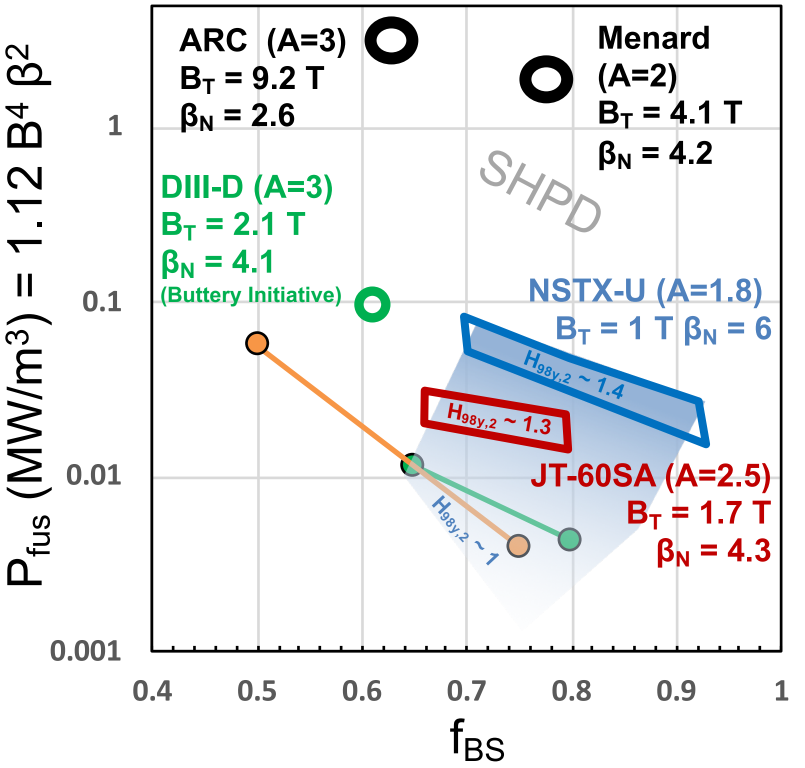
- Large f_{BS} regimes must be extended by two orders of magnitude in P_{fus} for CFPP
  - Larger f_{BS} relaxes constraints on external current drive, but requires higher self-organization



NSTX-U will provide critical data in the high-f_{BS} regime

- NSTX-U will access high f_{BS} with large self-organization
  - f_{BS} > 80% enables A = 2-3 SHPD using PNBI (Menard Initiative)
  - Explore synergy of broad current (low-l_i), broad pressure (high-β_N) with strong shaping and large edge q-shear
- Important to unify predictive modeling across aspect ratios in fully NI regimes
  - Transport and stability at low-A have distinct differences from conventional-A
  - "High- β" path could be transformative

Fully Non-Inductive

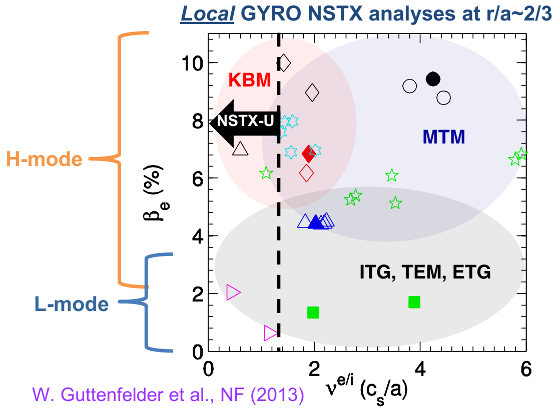


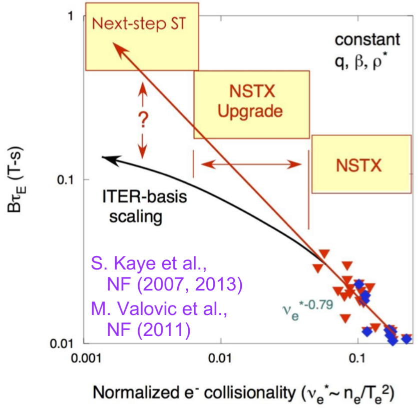
Transport at low-A is fundamentally different than transport at conventional-A

- Many features of low-A, high-β stabilize ES modes (ITG, TEM, ETG) in core transport
  - Neoclassical ion transport, MTM, KBM and EP modes drive electron transport

- Pedestal transport enhanced relative to predicted KBM transport
  - Wider pedestals ($\sim \beta_\theta$) beneficial for improved confinement and ELM-free operation
  - Enhanced TEM may also drive wider SOL [Chang, IAEA]

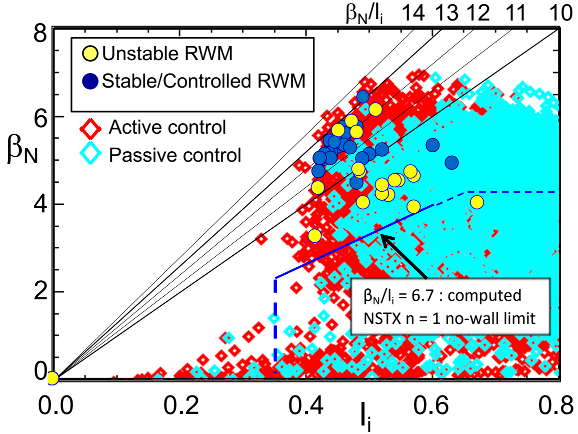
- Dimensionless confinement time scales inversely with collisionality at low-A ($\Omega_{ci}\tau_E \sim \nu_*^{-0.8}$)
  - Scaling extrapolates to an A=2 CFPP with H_{ST} = 0.9 equivalent to $H_{98y,2}$ = 1.75



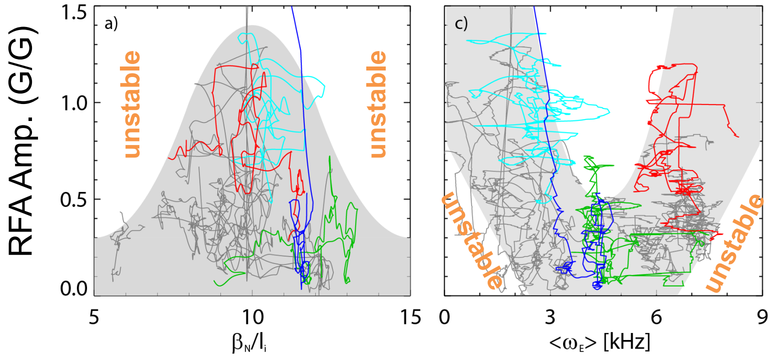


Passive stability at large β_N is a strong lever for a compact device

- $f_{BS} \sim \beta_N/l_i$ → Broad current and pressure profiles
  - NSTX achieved large β_N/l_i with $\beta_N / \beta_{no\text{-}wall} > 2$
- Stability increased as β_N/l_i → 10 at critical rotation
  - Kinetic stabilization of the RWM
  - Prediction that stabilization improves at lower collisionality will be tested on NSTX-U
- NSTX-U has expanded suite of RT control measurements and actuators
  - RT profile control using flexible NBI, density and shape actuators
  - Increased flexibility in the 3D field spectrum for EFC + rotation control



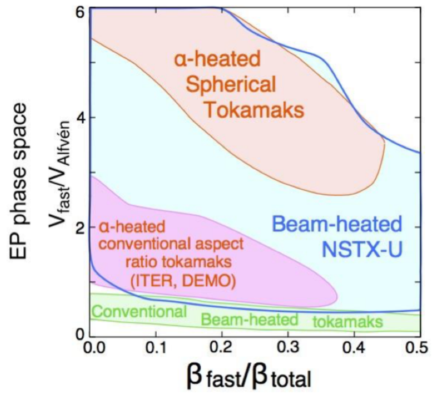
S. Sabbagh et al., Nucl. Fusion **53**, 104007 (2013)



J.W. Berkery, et al., PoP **21** (2014) 156112,
J.W. Berkery, et al., Phys. Rev. Lett. **106** (2011) 075004

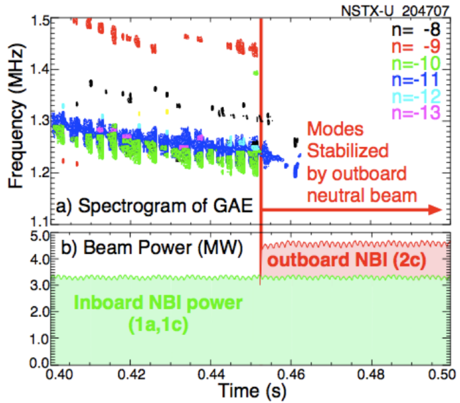
NSTX-U will access unique regimes in fast particle physics critical for prediction and optimization

- NSTX-U will produce and study EP modes relevant to alpha driven instabilities
  - Unique ST: 100 keV beams + RF
  - Important for ITER and CFPP burning-plasma optimization



~ (EP-instability drive)/(EP-instability damping)

- Modification of fast-ion distribution using tangential NBI can stabilize EP modes that enhance transport
  - Study and develop techniques to suppress fast ion driven modes



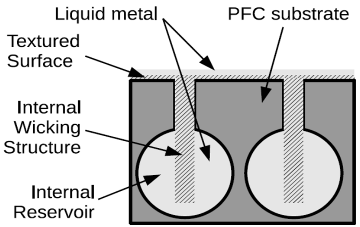
NSTX-U facility will aims to demonstrate an transformative divertor solution with liquid metal PFCs

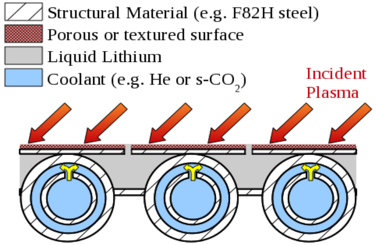
- Near-term boundary research focused on understanding edge transport and PMI with flexible divertor magnetic topology and surface chemistry
  - Expanded divertor coil set, divertor fueling, boundary diagnostics and carbon wall conditioning (B, Li) capabilities
  - Heat flux may exceed 30 MW/m^2 requiring heat flux mitigation solutions compatible with high performance

- Begin transition to liquid lithium PFCs in mid-2020s to investigate core-edge integration
  - Liquid lithium PFCs are a potentially transformative innovation enabling compact fusion systems
  - Potential to combine continuous particle pumping and self-healing PFC

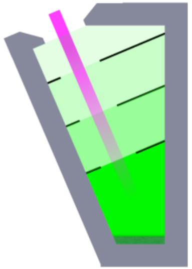
Liquid lithium technologies would evolve in tandem for eventual down-selection in late 2020s

- First phase would employ pre-filled heated high-Z tiles and midplane limiter with flowing lithium
  - Examine impact of evaporative Li surface on plasma performance
  - Advance development of flowing lithium systems and predictive understanding of particle and power exhaust





- Second phase would qualify an integrated liquid lithium solution for next-step compact devices
  - NSTX-U would replace all tiles for full high-Z coverage with a fast flow or slow flow (vapor box) divertor systems

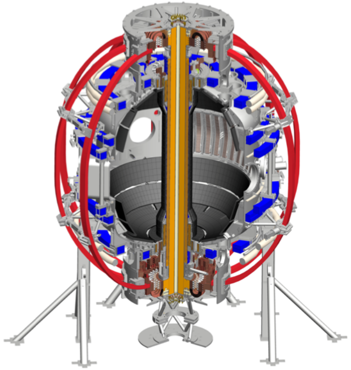


NSTX-U in the 2020s

- NSTX-U aims to demonstrate an integrated core-boundary solution for next-step devices and significantly advance predictive modeling that is unified with conventional-A devices by 2030
- Research operations will restart in 2021-22 and aggressively address near-term mission elements toward configuration optimization
  - Success accelerated by support of the domestic community
- Transition to LM PFCs in mid-2020s with expanded diagnostic suite
  - Redirection of program funding, on the order of $5 million/year
- Down-select for expansion of LM program (high-Z tiles, fast or slow flow LM in divertor) for demonstrating core-edge integration in late 2020s
  - Requires enhanced investment in the NSTX-U facility, broadening of technical and scientific staff with expertise in PMI and material science

Some sort of graphic?

- Arrows showing elements of domestic program (CPP initiatives) and how NSTX-U program fits in.



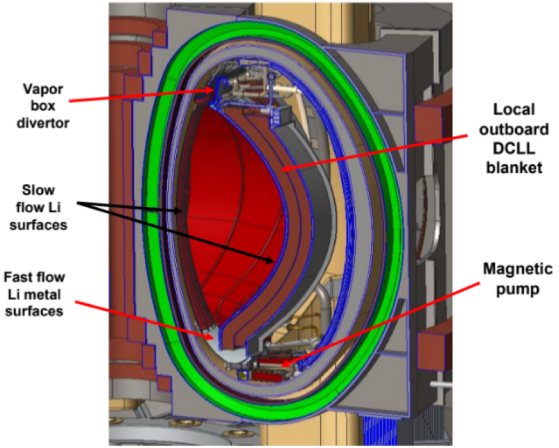


Figure 5 – Cross-sectional image of R=1m, A=2.4 SHPD concept capable of testing vapor box divertors, slow-flow LM first-walls, and fast-flow LM divertors – potentially simultaneously.

Global context of the NSTX-U Facility

- Upgrades to NSTX and MAST pursued in close coordination
  - MAST-U: baffled divertor and extensive boundary diagnostics and fueling control
  - NSTX-U: scenario performance and optimization with larger B_T, P_0 (3x larger), β, β_N, f_{BS}, β_N/l_i and lower ν^*
    - Enhanced RT profile control, NBI flexibility, RF heating, wall conditioning
  - Facilities retain important capability to perform similarity experiments

- Tokamak Energy pursuing small, high-field STs and magnet R&D

- Urania (Pegasus), LTX-β and international STs focus on innovation and physics basis at ultra-low A

- Close collaboration with scientific programs on conventional-A devices required to unify physics basis

- Aggressive expansion of the core-edge integration with liquid lithium PFCs would allow the U.S. to reclaim worldwide leadership in this area