# Overview of Recent Results from HSX and the Planned Experimental Program

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# Highlights

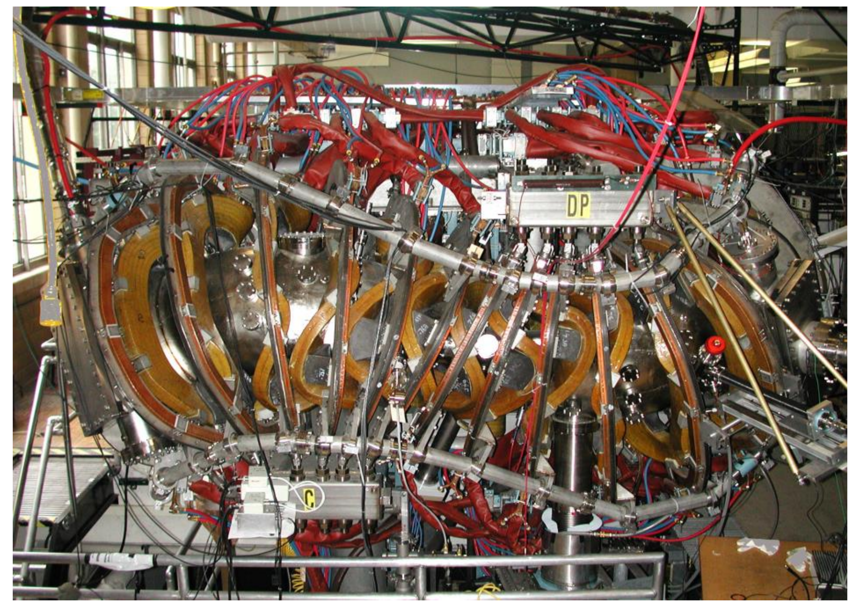
- Quasisymmetry results in reduced electron thermal diffusivity
- Hollow density profiles with peaked temperature profiles in mirror mode operation are attributed to neoclassical thermodiffusion
- Reduction of thermodiffusion with quasisymmetry results in peaked density profiles with peaked temperature profiles

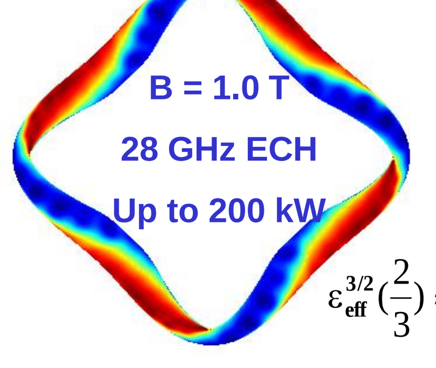
**Invited talk by J. Canik Friday morning**

- HSX has begun operations at the full design field of B=1.0 T
  - Thermal plasmas with $T_{e0}$ ~ 2keV; Poster by Likin
- New ECH transmission line expands available power; Poster by Radder
- Bootstrap current unwinds transform in QHS; Poster by Schmitt
- Good confinement of energetic particles leads to observation of MHD mode; Poster by Deng
- ITG/TEM + neoclassical predicts profiles in HSX; Poster by Guttenfelder

# Goals of HSX

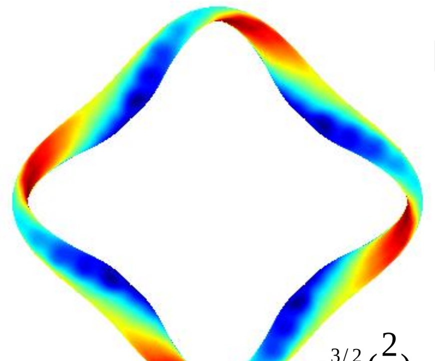
## Demonstrate the potential benefits of quasisymmetry






$\varepsilon_{\mathrm{eff}}^{3/2}\left(\frac{2}{3}\right) \approx 3 \bullet 10^{-4}$

$B = B_0\left[1 + \varepsilon_h \cos(N - m\iota)\phi\right]$



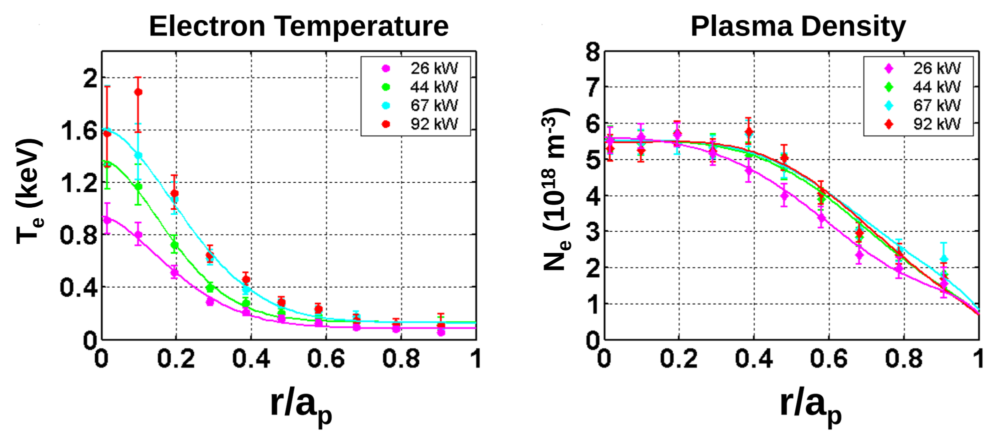

$\varepsilon_{\mathrm{eff}}^{3/2}\left(\frac{2}{3}\right) \approx 2 \bullet 10^{-2}$

$B = B_0\left[1 + \varepsilon_h \cos(N - m\iota)\phi + \varepsilon_M \cos(N\phi)\right]$

- HSX has a helical axis of symmetry in |B| and a resulting predicted very low level of neoclassical transport. $\iota_{\mathrm{eff}}$ ~3
- For experimental flexibility, the quasi-helical symmetry can be broken by adding a mirror field.

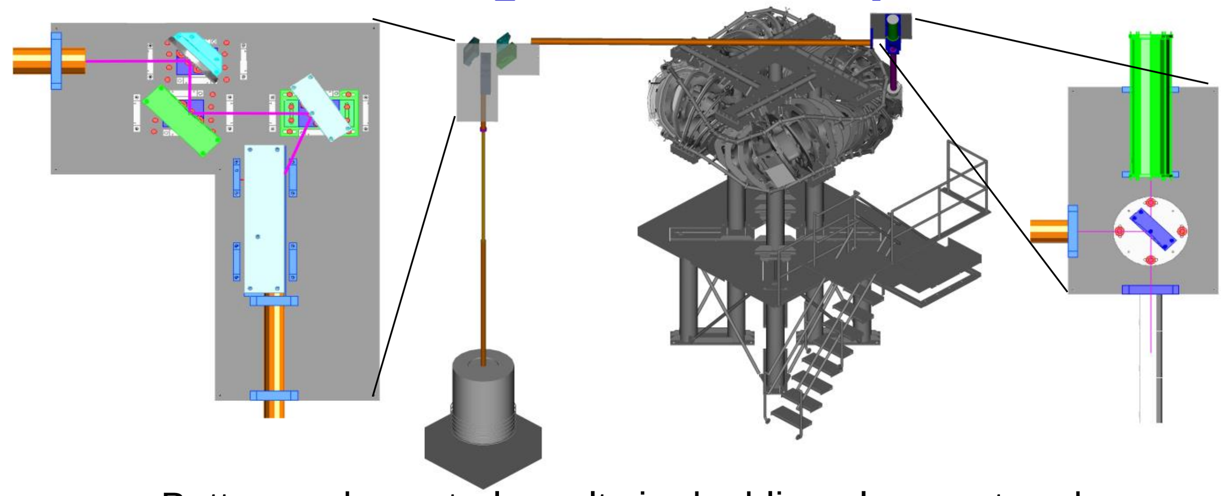
# Operations Upgrades

## HSX Now Operating at B=1.0T !




- Kinetic stored energy (from Thomson scattering) is close to that measured by the diamagnetic loop at all power levels to date
- At 92 kW of launched power the stored energy is about 110 J and the central electron temperature appears to be higher than 2 keV (TS limit at the moment)
- Plasma density is peaked and quite independent of absorbed power
- Plasma density profile is broader than that at 0.5 T

## Quasi-optical Transmission Line Permits Higher Power Operation



- Better mode control results in doubling plasma stored energy with same injected power
- Capable of transporting higher power to HSX without arcing
- Prototype for second line with steerable mirror for second ECH system (can modulate for transport studies)

## Diagnostic and Heating Upgrades

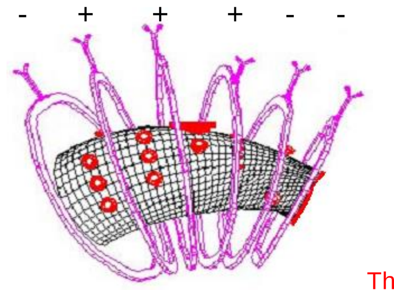
- 16 channel ECE diagnostic for B=1.0 T ready for installation
- Thomson scattering to be upgraded for measurement capability beyond the 2 keV initial design limit
- Reflectometer for core density fluctuations ready for installation
- Progress in CHERS system using DNB on loan from MST
- Possibilities of an HIBP system for HSX under investigation
  - Poster by Chen
- 2nd 200 kW 28 GHz ECH well underway (steerable/modulated)

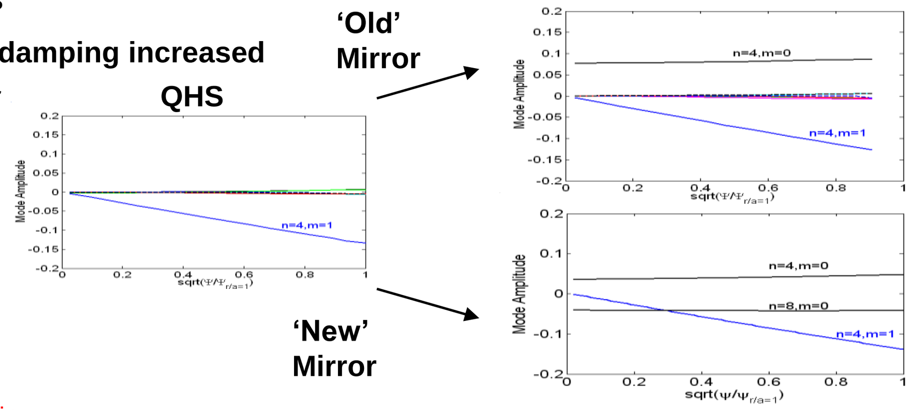
## New Mirror Configuration for Symmetry Breaking

- Phasing currents in auxiliary coils breaks quasihelical symmetry (n=4, m = 1) with n = 4 & 8, m = 0 mirror terms
- Neoclassical transport and parallel viscous damping increased

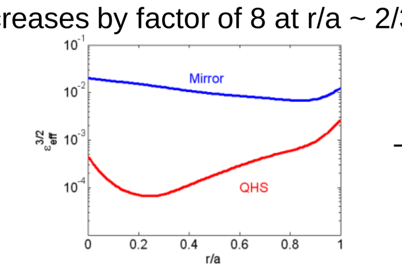
\+ \+ \+ - - - 'Old' Mirror

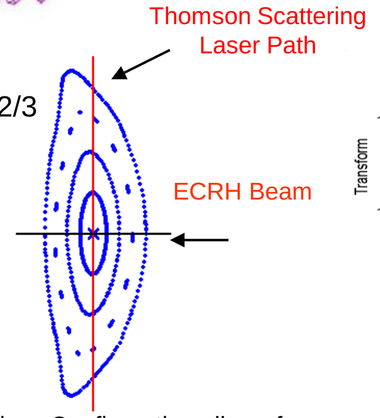
\- \+ \+ \+ - - 'New' Mirror



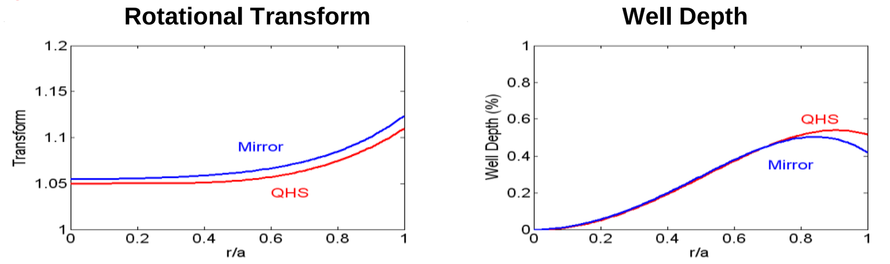



$\varepsilon_{\mathrm{eff}}$ increases by factor of 8 at r/a ~ 2/3



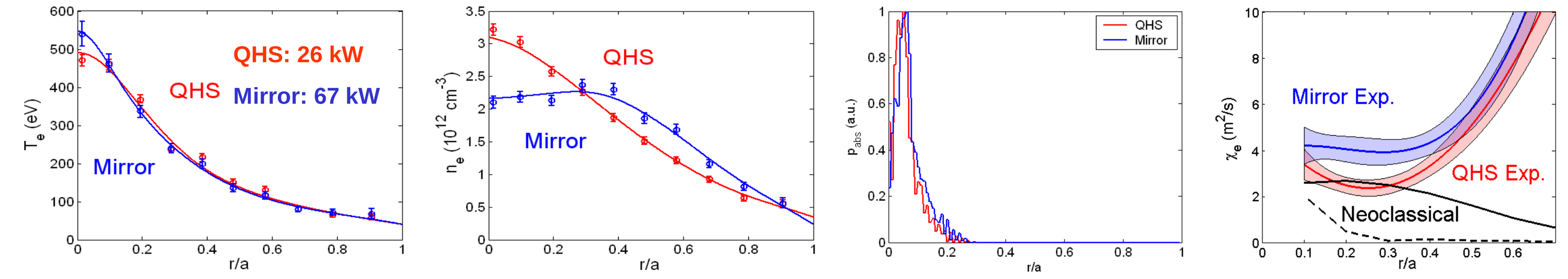

New Mirror Configuration allows for both on-axis heating and on-axis Thomson profiles




| | QHS | 'New' Mirror | |
|---|---|---|---|
| Transform (r/a = 2/3) | 1.062 | 1.071 | < 1% change |
| Volume (m³) | 0.384 | 0.355 | < 10% change |
| Axis location (m) | 1.4454 | 1.4447 | < 1 mm shift |
| $\varepsilon_{\mathrm{eff}}$ (r/a = 2/3) | 0.005 | 0.040 | Factor of 8 |

# Quasisymmetry Reduces Neoclassical Thermal and Particle Transport

## 2nd Harmonic ECH at B=0.5 T ; QHS lower thermal conductivity




**Temperature profiles matched between QHS and Mirror**

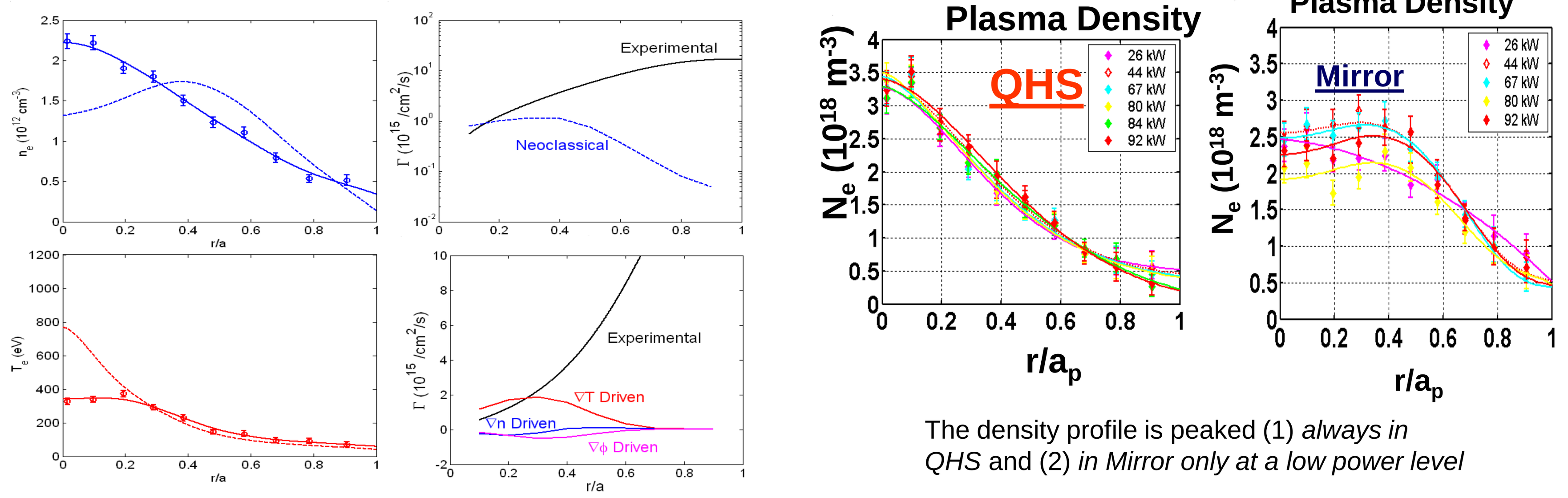
**Mirror required 2.5 times injected power**

**Density profiles don't match due to thermodiffusion (below)**

**Absorbed power profile from ray-tracing; total absorbed power from Thomson turn-off**

**QHS has lower core $\chi_e$**

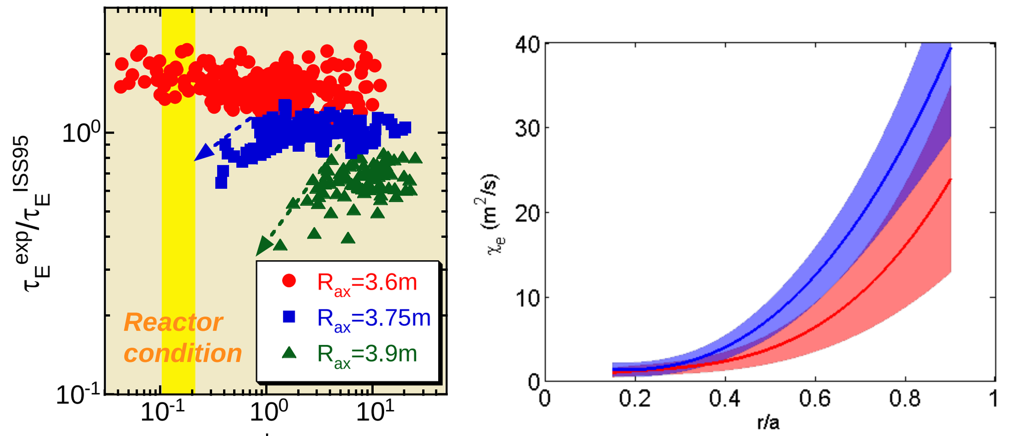
## Thermodiffusion drives hollow density profiles in Mirror




*The density profile is peaked (1) always in QHS and (2) in Mirror only at a low power level*

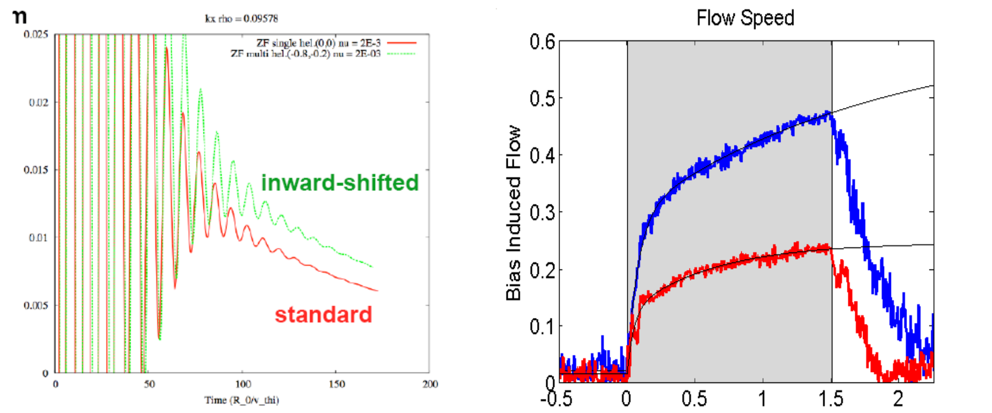
# Open Questions

## Does optimizing for neoclassical transport suppress turbulent transport?



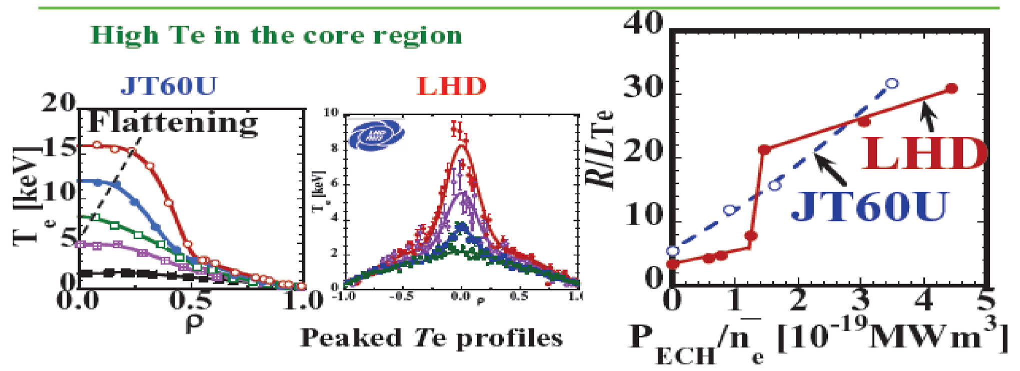

- LHD shows evidence of reduced anomalous transport with inward shift
- Our first experiments to test working hypothesis in HSX are encouraging but error bars are too high
- Improvements at B=1.0 T with more thermal plasma

## Does decreasing effective ripple decrease zonal flow damping?




- Sugama predicts decrease in zonal flow damping and turbulent transport with decrease in neoclassical transport confinement in LHD
- In HSX, we have already demonstrated decrease flow damping in quasisymmetric configuration. Will zonal flow damping also be reduced?

## Is it harder to get an electron root in a quasisymmetric stellarator?




- CERC (Central Electron Root Confinement) observed in CHS, LHD, TJ-II and W7-AS
- To date, no sharp transitions in temperature gradient scale length observed in HSX.
- What if we increase effective ripple and power?

# Summary

- We have demonstrated reduced particle transport and electron thermal conductivity in a quasisymmetric stellarator at B=0.5 T
- Have achieved ~ 2 keV central electron temperature at B=1.0 T with only 100 kW injected power
- Program evolving toward understanding role of reduced neoclassical transport on anomalous transport levels
- We have upgrades coming online in diagnostics and available heating power that will allow us to explore this issue

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