Experimental Plan and Recent Results from HSX

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HSX Project summary

Improved diagnostic implementation allows improved understanding of HSX plasmas

- 10 channel Thomson scattering allows a radial profile of T_e
- 9 channel microwave interferometer provides time-evolution of density profiles
- 4-channel ECE allows a sparse radial profile of T_e plus non-thermal contributions
- Hard X-ray pha for energy resolved hard-x-ray fluxes
- H_α toroidal and poloidal array
- 7 channel soft x-ray array

Confinement enhancement of the QHS configuration over the symmetry-broken Mirror configuration is seen in low density operation where a significant super-thermal tail is produced by the rf.

- Rf single-pass power absorption is very good at low densities where the absorption is dominated by the super-thermal tail population of electron – at low density 75% of the power is deposited into the super-thermal tail
- Hard X-ray signals up to 600 keV for QHS and only for 200 keV in Mirror mode. All Hard X-ray signals disappear at densities above 1.5 e^{12}/cc
- QHS breakdown is ~2x faster than Mirror – occurring at lower gas-fill pressures which lead to low density plasmas
- ECE data shows a 6 keV population for QHS but only a 3keV population for Mirror at low density
- ECE and Thomson scattering temperatures agree for r/a=.2 above ~1.5e^{12}/cc

Plasma Rotation by Biased Electrode

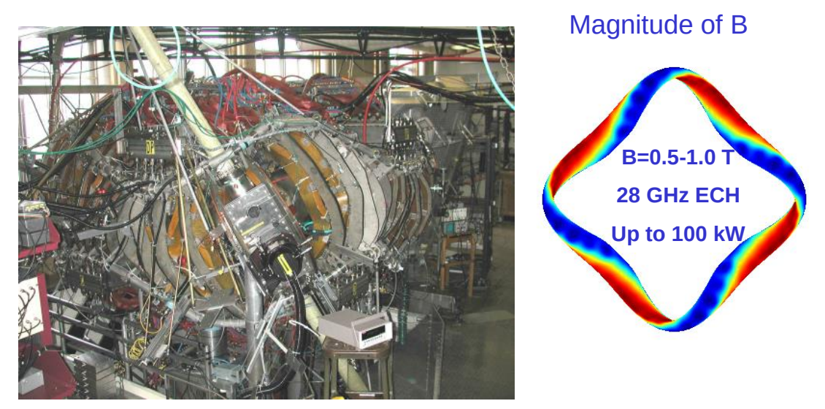
- Rotation is combination of the reintroduction of symmetry, combined with the damping effects of neutrals and anomalous viscosity/damping
- QHS flow damps more slowly, and rotates faster, for less driving force than the symmetry-broken mirror configuration

Improved plasma modeling with ASTRA and DEGAS codes at moderate plasma densities (>1.5 x10^{12}/cc)

- Experimental results consistent with Alcator-like scaling of anomalous transport (If $\tau \sim n = nT/P$, then: $T \sim P$ (independent of n) ; $\tau \sim n$; $W \sim nP$) – anomalous transport dominates the HSX plasmas
- Astra model predicts T_e profile well. Assumes $\chi_{e,anom} \sim 1/n_e$. Experimental Γ, D, T and τ are all generally consistent with the $\chi_{e,anom} \sim 1/n_e$ model
- Degas code predicts H and H_2 source rates, and diffusion coefficient, from H_α toroidal and poloidal array – $D \alpha n^{-.6}$ and D is independent of P.

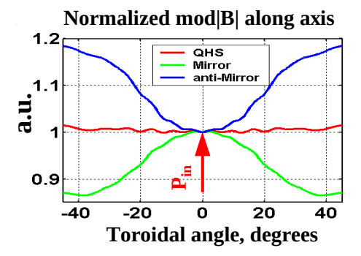
HSX Device

HSX is a Quasihelically Symmetric Stellarator



HSX has a helical axis of symmetry in |B| and a resulting very low level of neoclassical transport

Neoclassical Transport Can Be Increased with Mirror Field

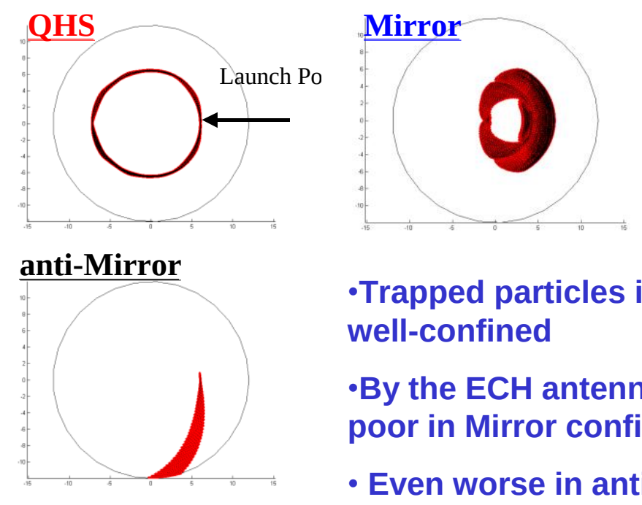


- Mirror configurations in HSX are produced with auxiliary coils in which an additional toroidal mirror term is added to the magnetic field spectrum
- In Mirror mode the term is added to the main field at the location of launching antenna
- In anti-Mirror it is opposite to the main field

HSX Parameters

Major Radius	1.2 m
Minor Radius	0.15 m
Volume	0.44 m^3
Magnetic Field	0.5 T
Field periods	4
Coils/period	12
RF Power	<100 kW
RF pulse length	< 50 ms

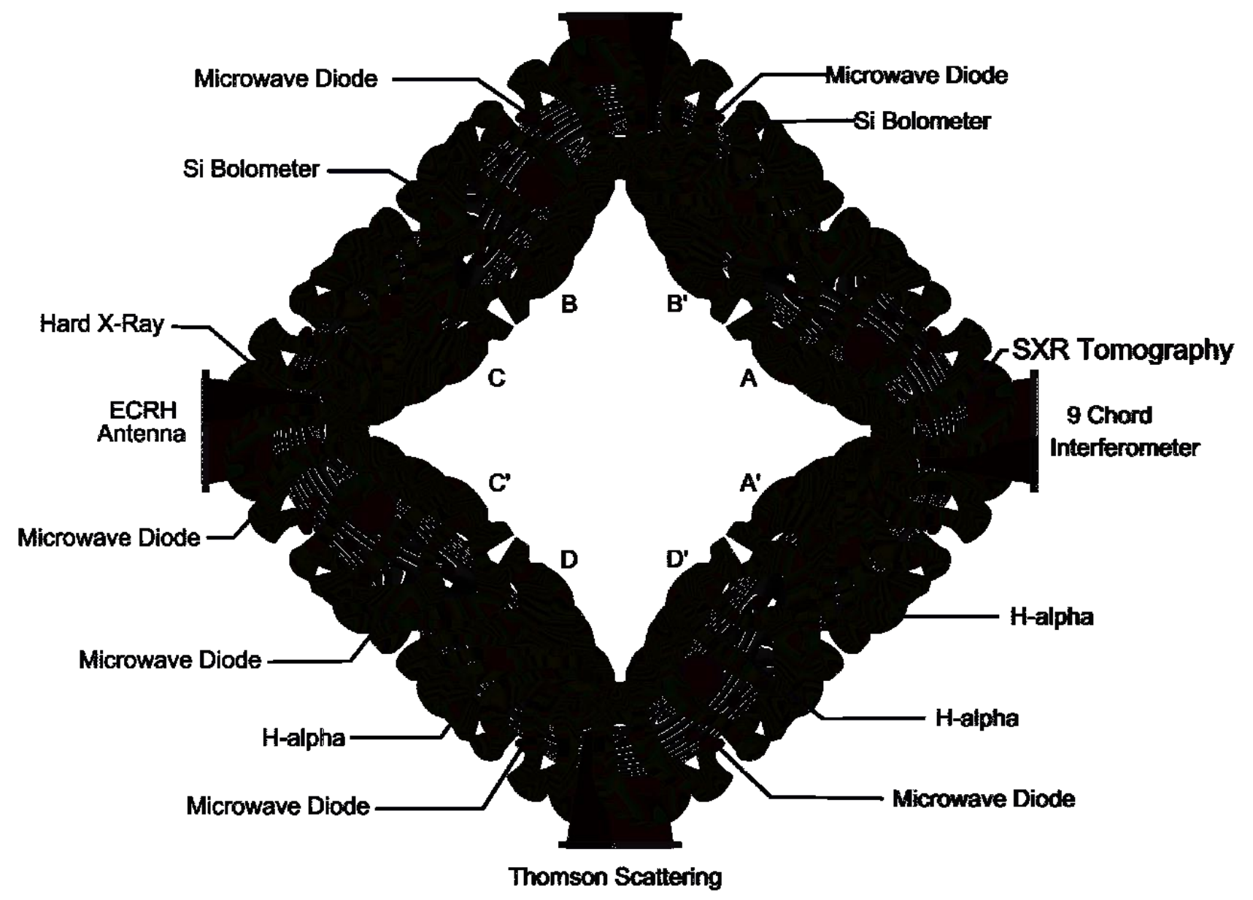
Trapped Particle Orbits



- Trapped particles in QHS are well-confined
- By the ECH antenna, orbits are poor in Mirror configuration;
- Even worse in anti-Mirror

HSX Diagnostics

Diagnostic location



- 10 channel Thomson scattering system for T_e up to 3keV – based on the DIII-D divertor Thomson system.
  - Currently providing radial profiles at one time during a plasma shot - Designed for 50 hz double-pulse operation
- 9 chord μ-wave interferometer provides full time evolution of plasma density profiles
- A 4-channel ECE system provides T_e:r for thermal plasmas, and a guide to non-thermal emissions by T/S comparison
- H_α poloidal and toroidal array for plasma source rate distribution and, from DEGAS, a diffusion coefficient
  - 7 detectors in toroidal array and 9 detectors in the poloidal array
- An array of 20 silicon photodiodes forms a multichord array of Soft X-ray detectors
  - 7 currently used for initial testing – will be expanded to using all 20 diodes in the array, and 3 or 4 arrays for tomographic reconstruction
  - 5 micron Be filter gives 400 eV lower energy limit, and the photodiodes limit the upper energy to <2 keV
- A Hard X-ray pha detector provides X-ray energy data from 20 to 900 keV
- Edge probes provide basic edge parameters, and allow examination of fluctuation induced transport
  - A multi-probe 'Gundesrup' probe is used for plasma flow analysis
  - Poloidal and radial probe arrays provide potential and density information, and correlated fluctuation measurements

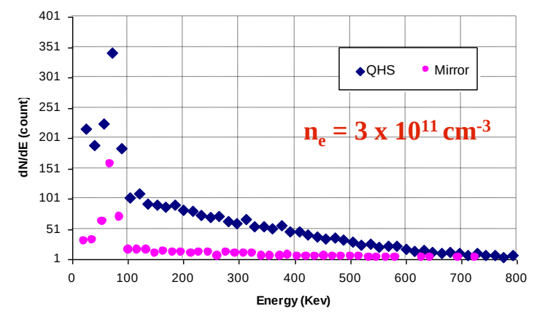
Major Results

Low density shows a strong non-thermal electron population , and improved confinement of QHS over Mirror

Different Hard X-ray Characteristics in QHS and Mirror

The Hard X-ray spectrum for QHS and Mirror, central heating shows:

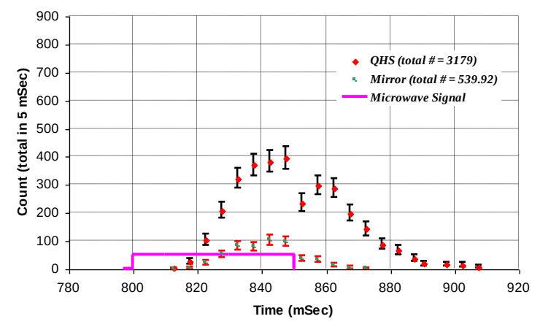
- Density of superthermal electrons is higher in QHS than in Mirror.
- Electrons are heated to higher energies in QHS than in Mirror
- The antiMirror case has a very small signal – in the noise



Property	QHS	Mirror
Max. Intensity (number)	~ 351	~ 151
Max. Energy (KeV)	~ 600	~ 100

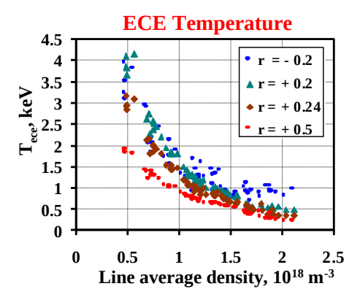
Hard X-ray Intensity Shows Improved Confinement in QHS Over Mirror Mode

- Hard X-ray signals show strong evidence for the existence of superthermal electrons in both QHS and mirror configurations (central heating).
- Similar input power density in both cases.
- The confinement of superthermal electrons in QHS is better than Mirror case.

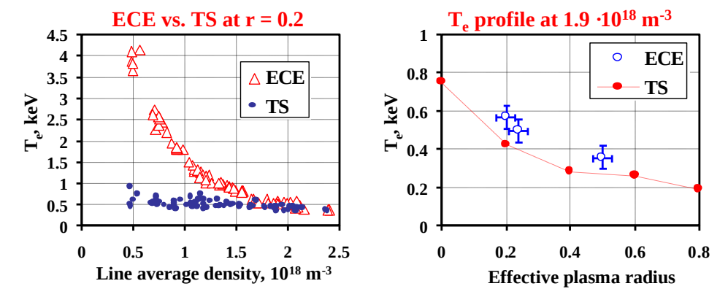


Property	QHS	Mirror
Max. Intensity (number)	~ 391	~ 102
decay time τ (msec)	13.0	5.3

Electron Temperature in QHS

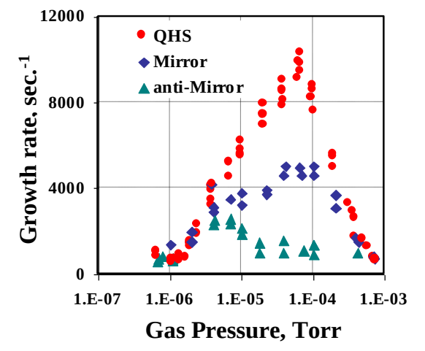


- ECE temperature drops with plasma density. T_{ece} at r = 0.2 at low and high plasma density differs from each other by a factor of 8
- Electron temperatures measured by Thomson Scattering and ECE are in a good agreement only at high plasma density (>1.7·10^{18} m^{-3})



Neutral Gas Breakdown

Motivation: (1) to study the particle confinement
(2) to study the physics of plasma breakdown by X-wave at the second harmonic of ω_{ce}



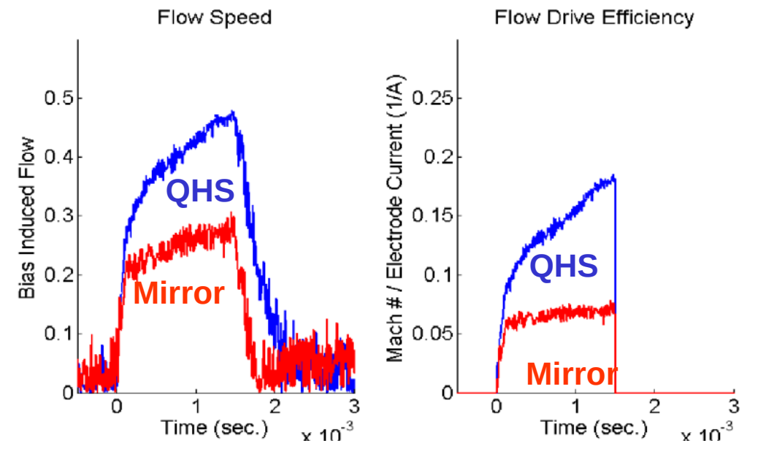
- Growth rate is determined from exponential fit to the interferometer central chord signal
- In QHS mode the growth rate is twice as that in Mirror
- In anti-Mirror mode the gas breakdown occurs with a very low growth rate

Major Results

Plasma flows

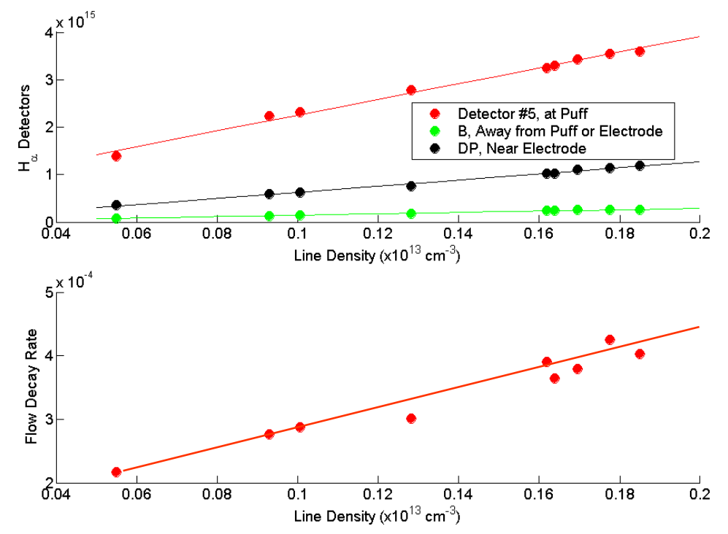
QHS Flow Damps Slower, Goes Faster For Less Drive.

- QHS Flow Rises and Damps More Slowly
- Flow Goes Faster For Per Unit Drive



QHS Damping Does Not Appear to Scale with the Neutrals

- H_α signal is linear in the density⇒neutral density approximately constant.
- See Poster by J. Canik for more details on the H_α system and interpretation.
- Flow decay time becomes longer as density increases.

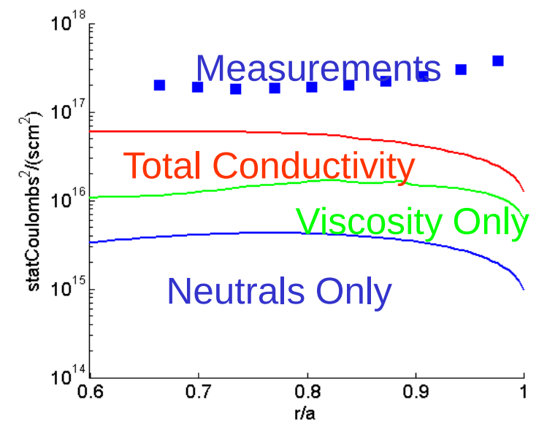


QHS Modeled Radial Conductivity agrees to a Factor of ≈3-4

- Define the radial conductivity as

$$R = \frac{\langle \vec{J} \cdot \vec{\nabla} \psi \rangle}{d\Phi / d\psi}$$

- Combination of neutral friction and viscosity determines radial conductivity.
- Mirror agreement is somewhat better.



QHS Damps Less Than Mirror; Some Physics Besides Neoclassical and Neutral Damping Appears to be Necessary to Explain the QHS Data.

Higher density plasmas exhibit thermal plasma properties and Alcator-like anomalous transport

Future directions