# Confinement of fast ions in the HSX stellarator

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## Is ICRH feasible in HSX?

**ICRH antenna design**

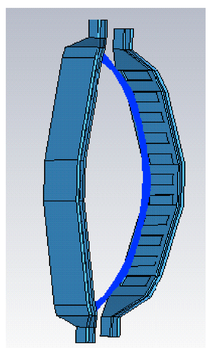


Figure by courtesy of Dr. S.Diem

with help of Prof. S.Murakami of Kyoto University

### Motivation

- ❑ To run HSX at higher density
- ❑ With the ion root, differences in neoclassical transport between QHS and Mirror configurations may be more pronounced
- ❑ To improve ion confinement, if possible, by tweaking symmetry-breaking terms in the QHS spectrum

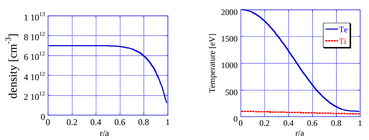
### Initial Steps

- ❑ Antenna design is in progress in collaboration with Drs. D.Rasmussen and S.Diem of ORNL
- ❑ 5 kW source will be used for R&D. The transmitter (100 kW / 5-30 MHz) is available now
- ❑ First calculations on confinement of high energy ions and ICRH efficiency in HSX plasma have been made

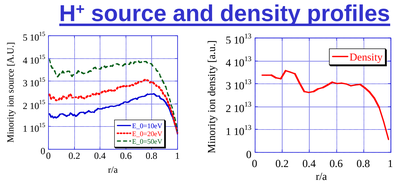
## GNET Results

- Drift kinetic equation is solved by Monte-Carlo method
- AURORA code is used to determine the minority particle source
- A simple model based on TASK/WM code is employed to estimate the ICRH term
- Charge exchange and direct orbits loss are included
- In HSX plasma the ICRH efficiency decreases with power
- There is a weak dependence of the efficiency on B

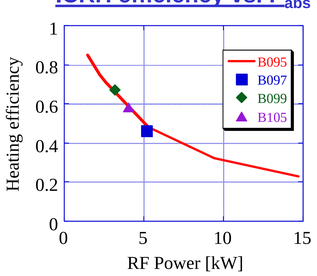
**Plasma density and temperature profiles**



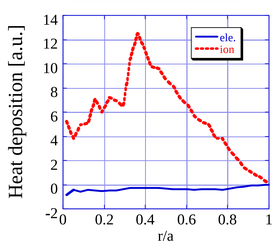

**H$^+$ source and density profiles**




**ICRH efficiency vs. $P_{abs}$**



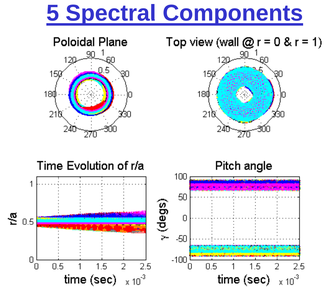

**Heat flux profile**



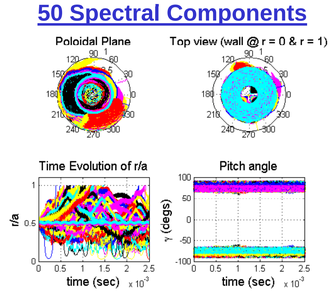

## Single Particle Drift Orbits

### Effect of Higher Harmonics

**5 Spectral Components**

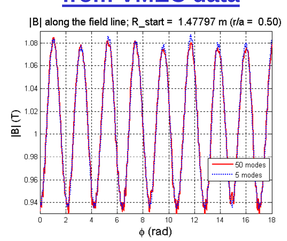



**50 Spectral Components**



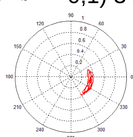

144 drift orbits: 5 keV particles distributed uniformly in poloidal and toroidal directions start at r/a = 0.5 with the pitch angle of +80 or -80 degrees

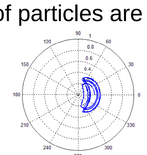
**Reconstructed |B| from VMEC data**




- Confinement of high energy ions drastically depends on a presence of higher harmonics in the mod B spectrum
- All particles are well confined in case of 5 spectral modes while with 50 harmonics 22% of launched particles travelled beyond the last closed surface
- For comparison to equivalent tokamak (main spectral mode 1,4 is replaced with 0,1) 34% of particles are poorly confined

QHS Banana Orbit

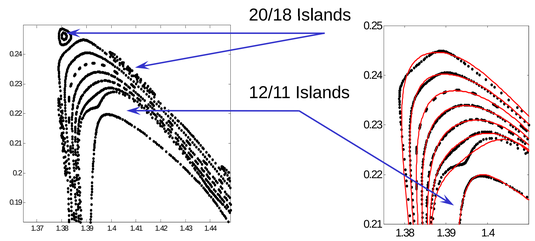




Tokamak Banana Orbit

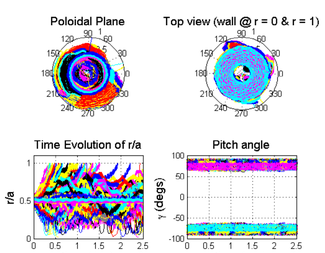
### Edge Islands Spoil VMEC Spectrum

**Fragments of the flux surfaces from the line following code and DESCUR fit**



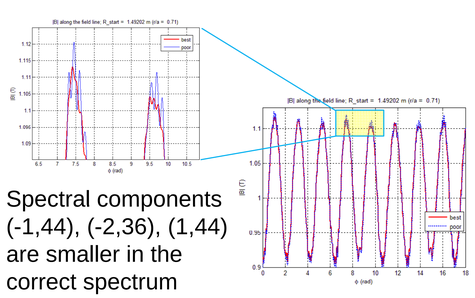

- DESCUR finds 2-D Fourier spectral representation of LCFS
- Some surfaces are matched well by DESCUR with 16x25 modes (poloidal x toroidal ) but some surfaces aren't
- Shape of the LCFS near island gives rise to artificial spectral components

**Orbits with artificial harmonics in the mod B spectrum**




75% of all particles are still confined

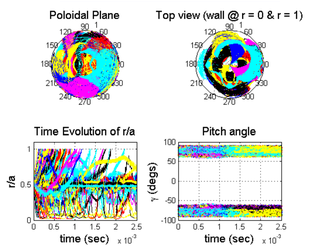
**Reconstructed |B| in best and poor fits to LCFS**



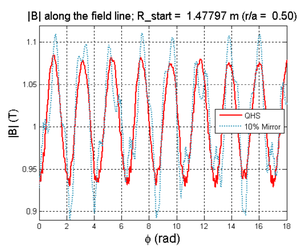

Spectral components (-1,44), (-2,36), (1,44) are smaller in the correct spectrum

### In QHS 78% of 5 keV ions are well confined while in the configuration with broken symmetry only 44%

**Orbits in 10% Mirror**




**Mod B in QHS and 10% Mirror**




## Summary

- Collisionless high energy ions are well confined in QHS --- 70% of 10 keV ions stay within the LCFS for 2.5 msec
- Initial optimization of the QHS spectrum to improve the fast ion confinement showed little effect. This work will be continued
- Intensive calculations of ion drift orbits will be made on the Cray XT4
- GNET results still need to be benchmarked

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