



Modeling of High-Power Fundamental O-mode ECRH Plasmas in the HSX Stellarator



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1. Abstract

Hard x-ray and ECE measurements provide evidence of suprathermal electron populations in the HSX stellarator for low density, 100 kW fundamental O-mode ECRH. A five-dimensional Fokker-Planck code, GNET¹, is used to calculate the deviation from a Maxwellian background distribution via a Monte Carlo technique. Calculated electron distribution functions are presented for low line average density, high-temperature plasmas with low collision frequencies in the heating region. Calculated X-ray bremsstrahlung emission spectra and electron cyclotron emission spectra will be presented for non-Maxwellian electron distribution functions obtained with GNET and compared to measured spectra.

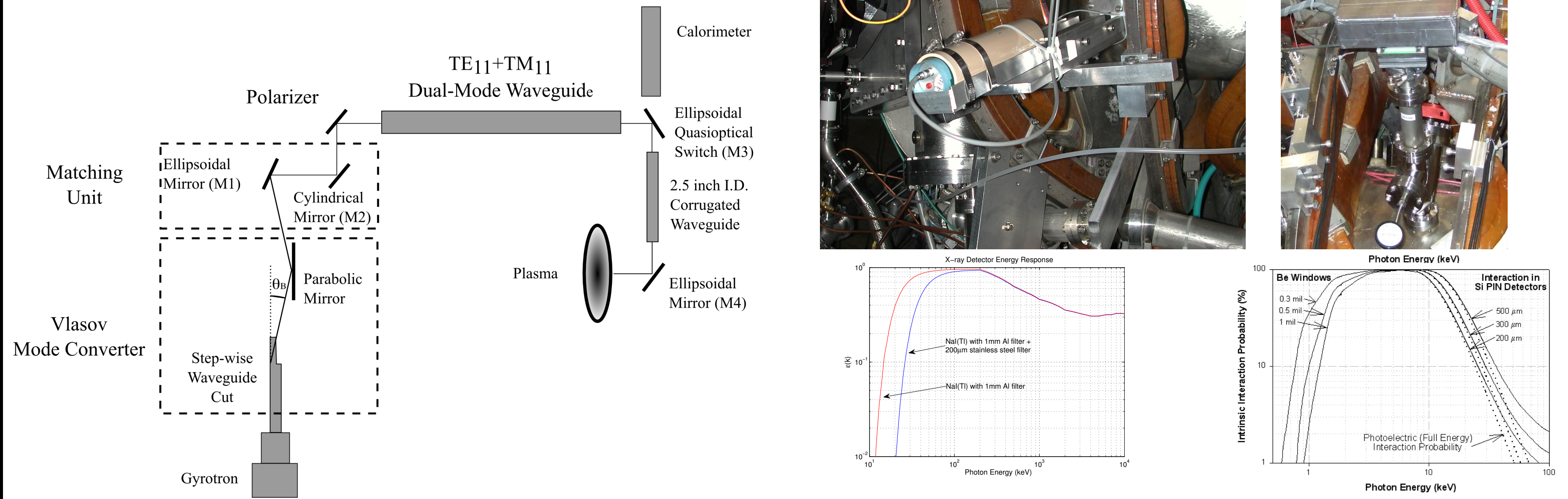
2. Background

The GNET Fokker-Planck code calculates the deviation from a Maxwellian electron distribution function in three-dimensional stellarator geometries via a Monte Carlo method. This technique allows calculation of electron distribution function and ECH-driven fluxes in flux coordinates, an important feature for comparing configurations with and without quasi-helical symmetry in HSX. The Monte Carlo technique is computationally intensive and requires large numbers of test particles to ensure numerical noise is below features in the resulting distribution functions.

3. Plasma Heating and Diagnostics

ECH System

- 2x 28 GHz Varian (now CPI) gyrotron microwave sources.
- Line 1: fixed launcher at midplane
- Line 2: steerable launcher below midplane
- Fundamental O-mode heating, $B_0 = 1$ Tesla
- Hybrid quasioptical waveguide
- 25 kW to 100 kW launched ECH power
- 50 ms pulse length



[1] S. Murakami, U. Gasparino, H. Idei, S. Kubo, H. Maaßberg, N. Marushchenko, N. Nakahima, M. Romé, and M. Okamoto. 5-D simulation study of suprathermal electron transport in non-axisymmetric plasmas. Nuclear Fusion, 40(3Y):693–700, 2000.

4. Calculating the Electron Distribution Function with GNET

- GNET calculates the deviation from a Maxwellian electron distribution such that:

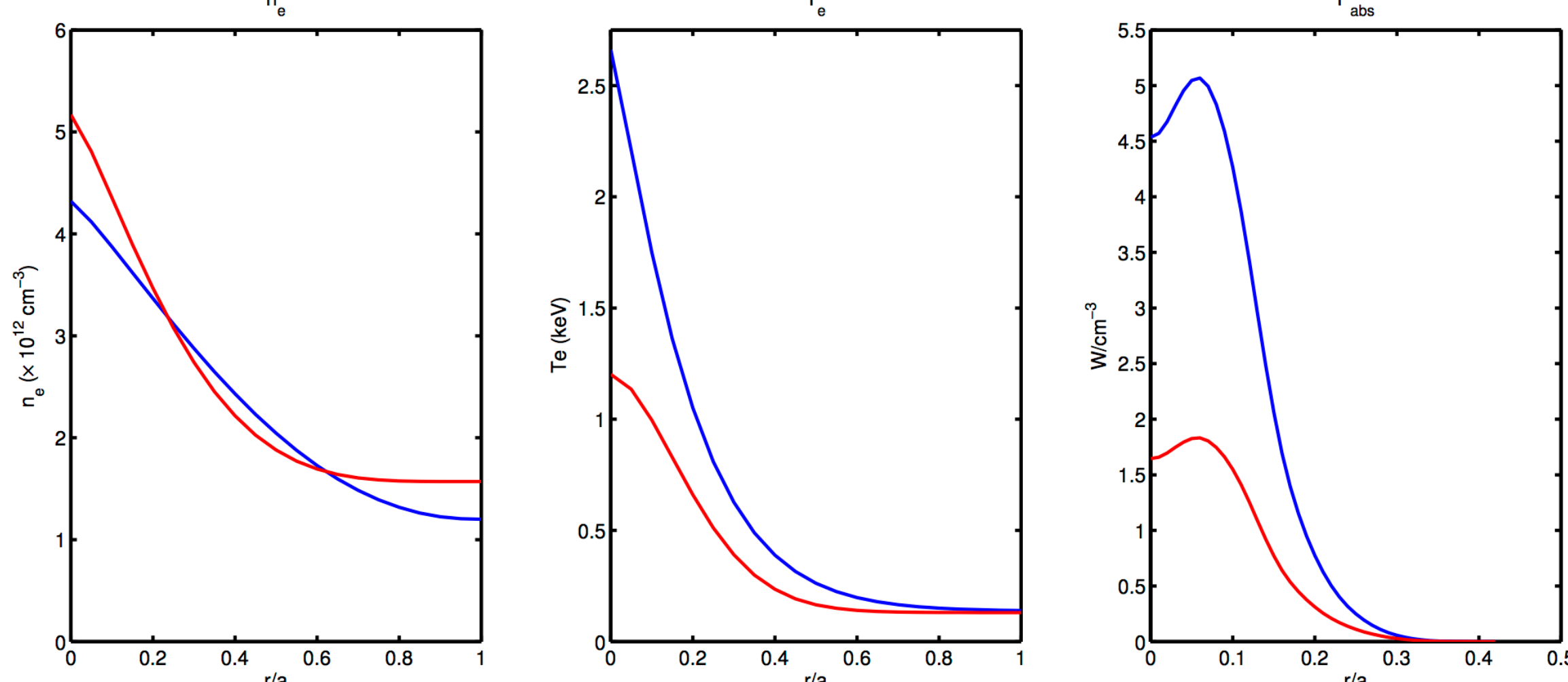
$$f_{tot.}(\mathbf{x}, v_{\parallel}, v_{\perp}, t) = f_0(r, v^2) + \delta f(\mathbf{x}, v_{\parallel}, v_{\perp}, t)$$

$$\frac{\partial \delta f}{\partial t} + (v_d + v_{\parallel}) \cdot \frac{\partial \delta f}{\partial \mathbf{x}} + \dot{\mathbf{v}} \cdot \frac{\partial \delta f}{\partial \mathbf{v}} - C^{coll}(f, \delta f) = S_{ECH}^{ql}(f_0)$$

- GNET uses a Green's Function technique to calculate δf :

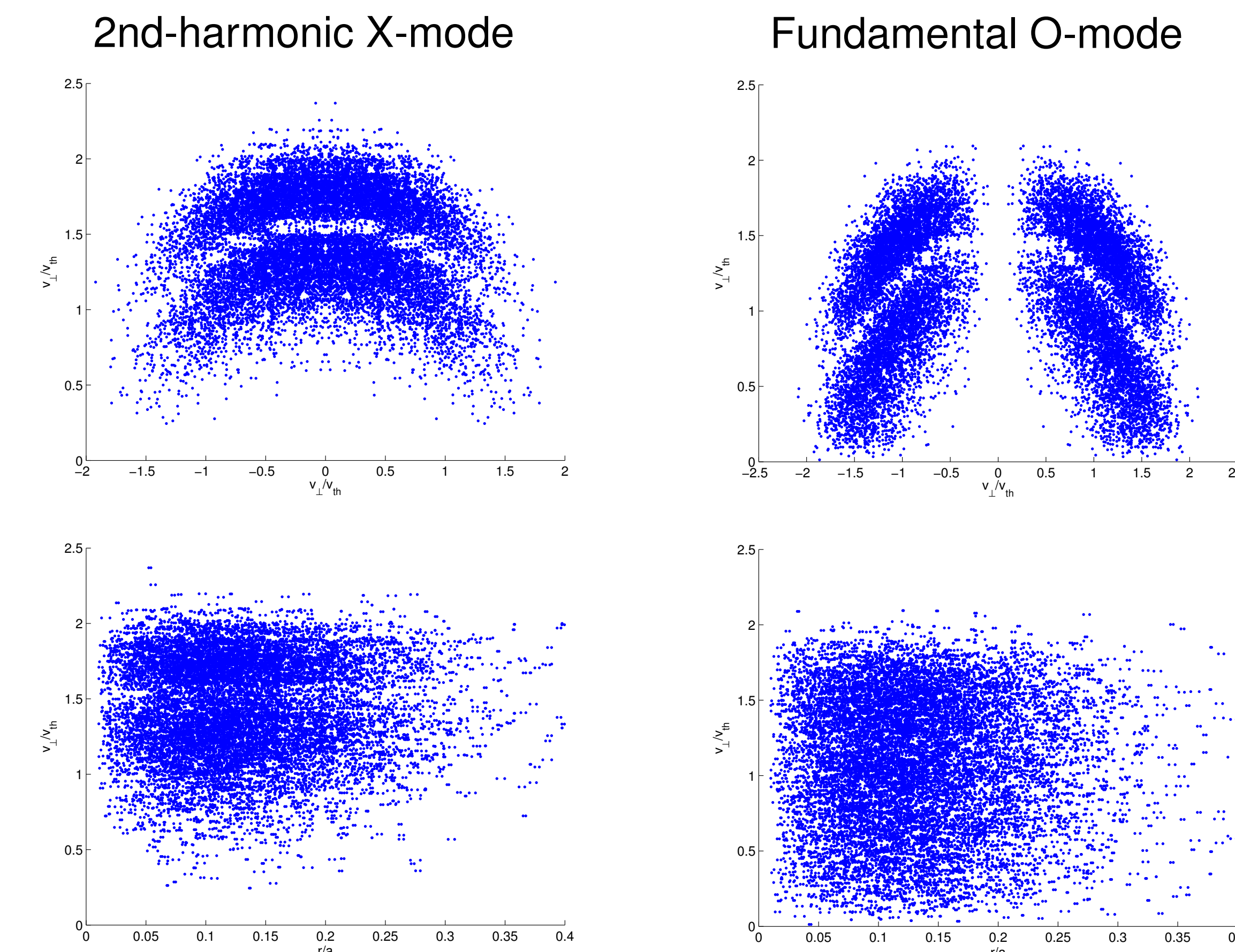
$$\frac{\partial \mathcal{G}}{\partial t} + (v_d + v_{\parallel}) \cdot \frac{\partial \mathcal{G}}{\partial \mathbf{x}} + \mathbf{v} \cdot \frac{\partial \mathcal{G}}{\partial \mathbf{v}} - C^{coll}(\mathcal{G}) = 0$$

$$\delta f(\mathbf{x}, \mathbf{v}, t) = \int_0^t dt' \int d\mathbf{x}' \int dv' S_{ECH}^{ql}[f_0(r', v'^2)] \mathcal{G}(\mathbf{x}, \mathbf{v}, t - t' | \mathbf{x}', \mathbf{v}')$$



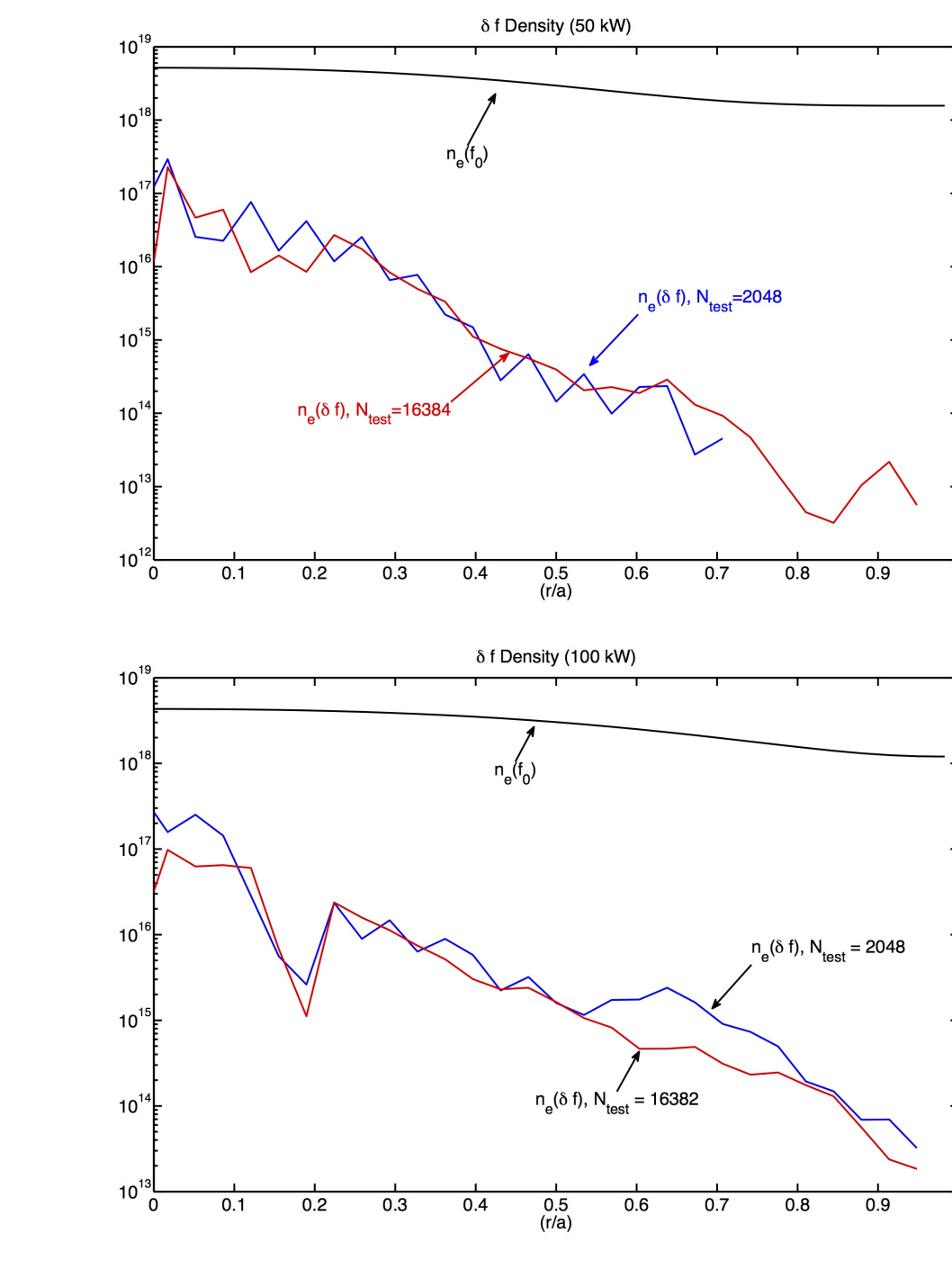
5. GNET Particle Source Distribution

- The test particles are initialize in $(\mathbf{x}, v_{\perp}, v_{\parallel})$ space.
 - 2nd harmonic X-mode particles have large $v_{\perp}$.
 - Fundamental O-mode particles increase both $v_{\perp}$ and $v_{\parallel}$.
 - Source particles are localized around magnetic axis, the region of highest power deposition for on-axis ECH.
- $S_{ECH}^{ql}(f_0)$ is a function of the stationary background Maxwellian electron distribution.



- A 3-D absorbed microwave power profile for ECH is calculated using electron temperature and density profiles, $T_e(r)$ and $n_e(r)$.
- Quasilinear heating model uses absorbed microwave power profile from a 3-D ray-tracing code.

6. GNET Results



7. Future Work

- A soft X-ray detector is available to measure photon energy in the range of 2 keV < k < 10 keV, where GNET predicts the largest deviations from a Maxwellian in HSX.
 - X-ray detector system needs calibration in HSX magnetic environment.
 - A Python interface to the HSX data system is being written to utilize an Innovative Integration high-speed digitizer system.
- Simulate additional HSX configurations:
 - QHS and Mirror mode
 - High and low plasma density
 - 50 kW to 100 kW, single and dual source configurations
- Investigate additional source terms in quasilinear heating operator to account for high energy X-ray spectra observed in low density $2 \times 10^{18} m^{-3}$, 100 kW ECH

