Numerical Modeling of GAE modes

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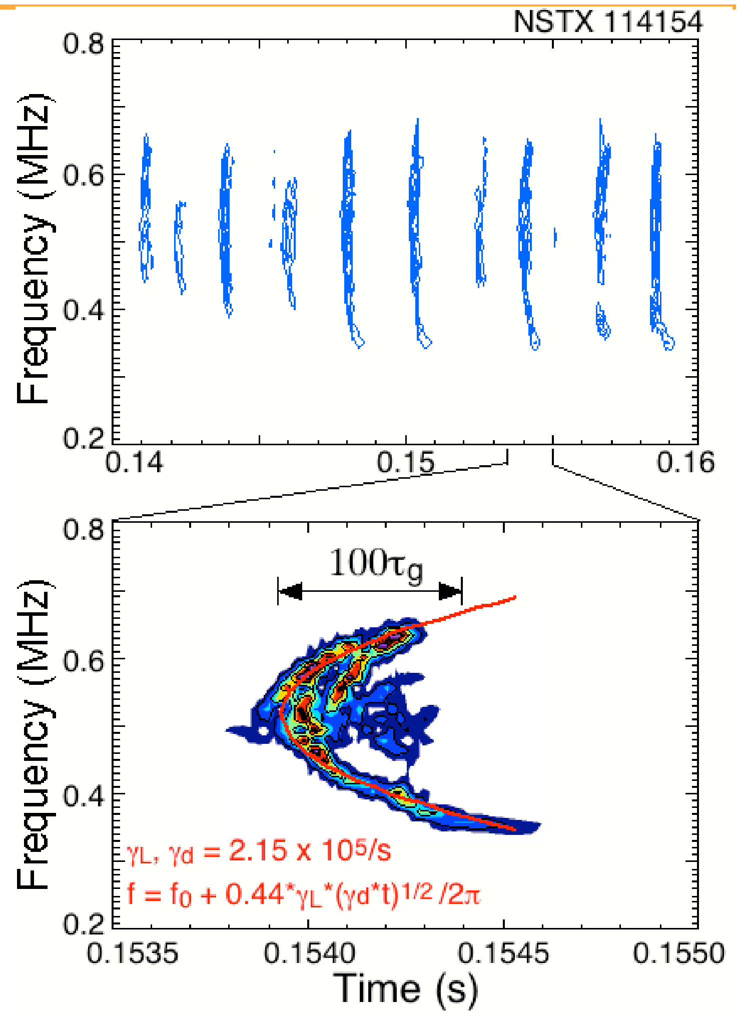
NSTX Results/Theory Review, PPPL August 2008

Most unstable mode in HYM simulations compares well with experimental results for NSTX 114147

• Measured toroidal number n=5 with frequency ω=480kHz (plasma frame) agrees with simulation results ω=403-530kHz.

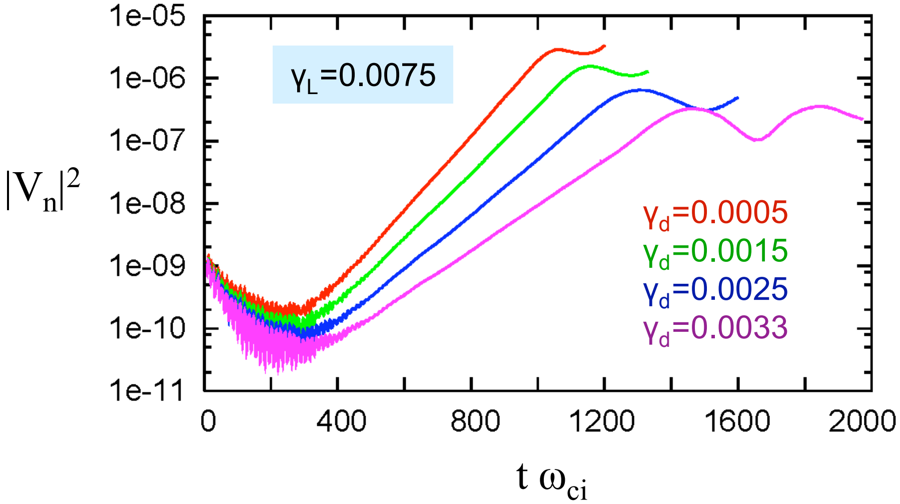
• Wave propagates opposite to the beam injection direction ie $\omega/k_{||} < 0$ (GAE mode).

• Linear growth rate is inferred from frequency chirping: $\gamma \sim 2.15 \times 10^5$ 1/s [E. Fredrickson’05 , Berk, IAEA'06] compares well with numerically calculated $\gamma \approx 1.54 \times 10^5$ 1/s.

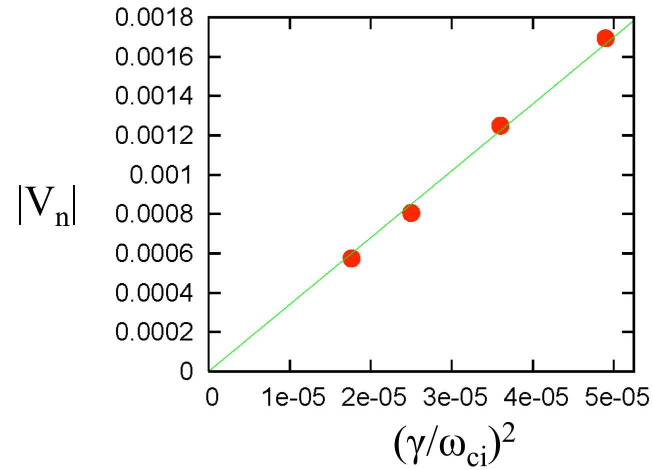


Up and down chirp observed during early NBI on NSTX.[E. Fredrickson’05].

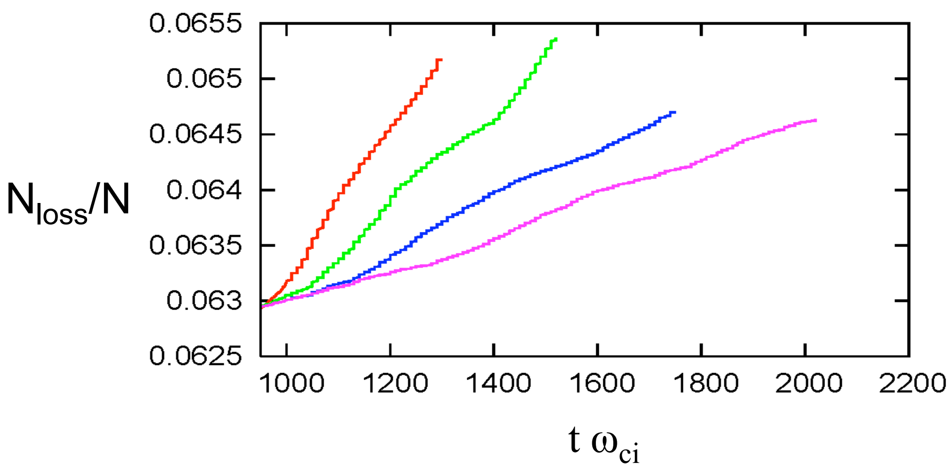
Simulations show nonlinear saturation of GAE due to particle trapping



Time evolution of kinetic energy from four nonlinear simulations with different damping parameter (viscosity).

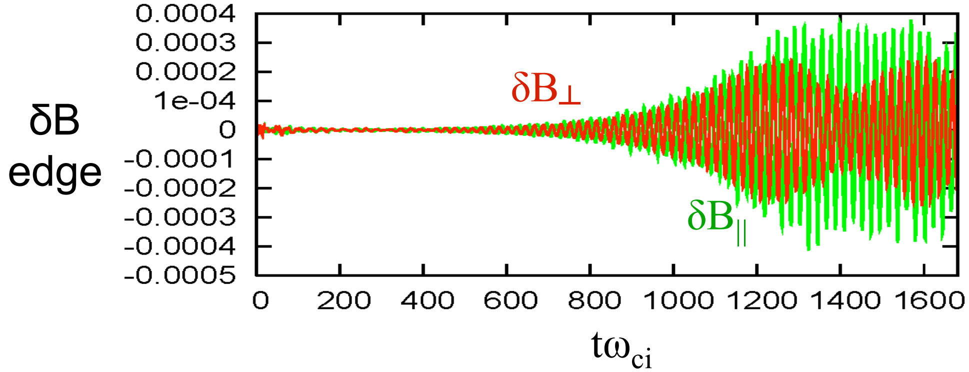


Saturation amplitude vs γ^2 (n=4, m=-2).



Fraction of lost beam ions vs time from same set of nonlinear simulations. GAE-induced losses ~ 0.2% for $\Delta t \sim 2/\gamma_L$.

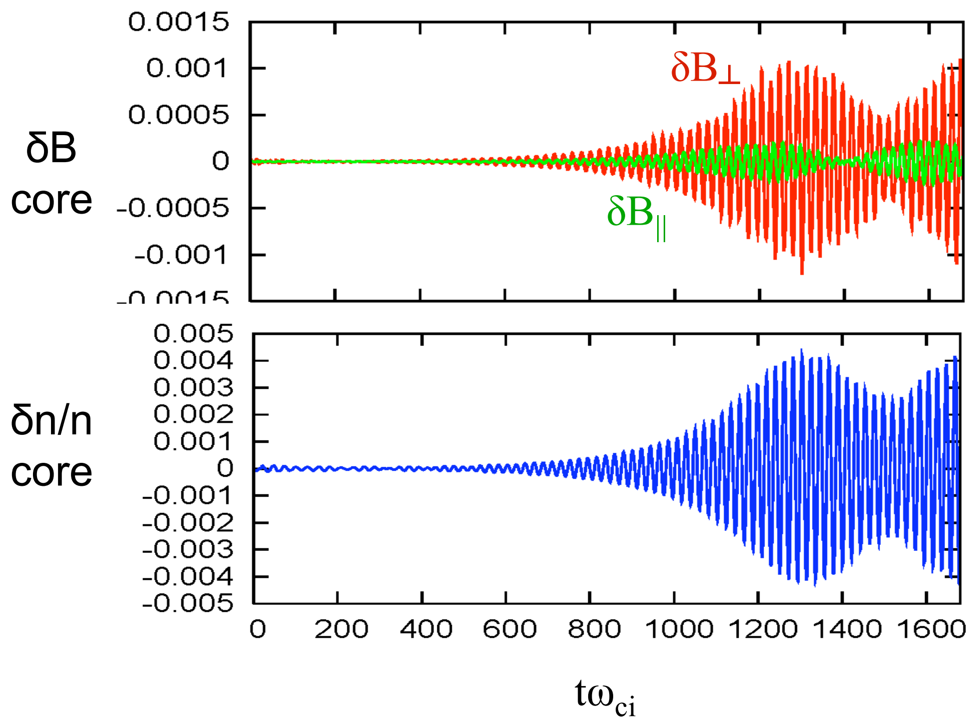
Magnetic field and density perturbations (case #3)



Simulations with **n=4 m=-2**

$\gamma = 0.005\omega_{ci}$ and $\omega = 0.3\omega_{ci}$

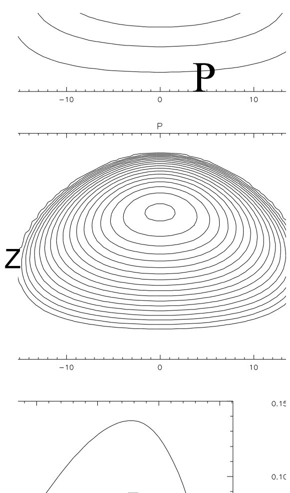
$\gamma_L = 0.0075\omega_{ci}$
$\gamma_d = 0.0025\omega_{ci}$

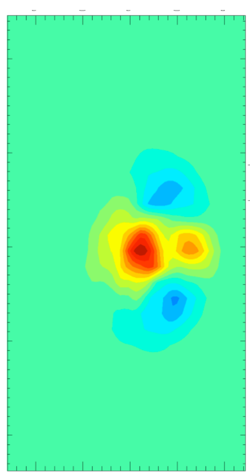


At peak amplitude $\delta B_\parallel < 1/3\ \delta B_\perp$; at the edge the compressional component dominates $\delta B_\parallel > \delta B_\perp$.

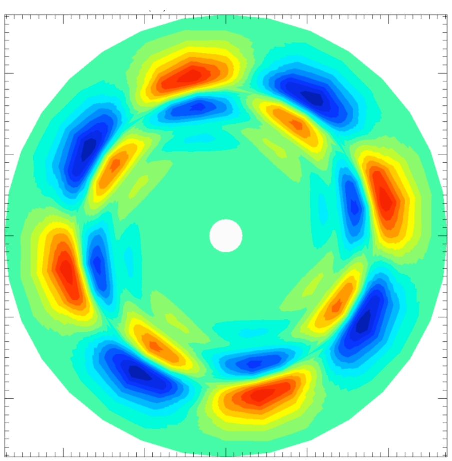
Mode structure

Linear



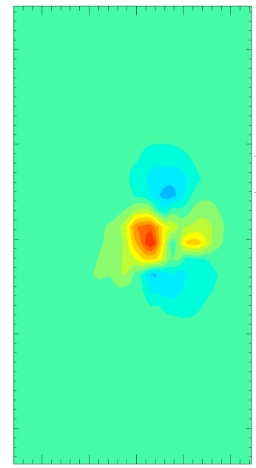


δP

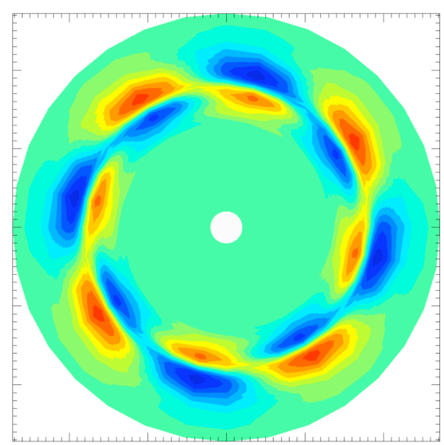


δV_R

Nonlinear



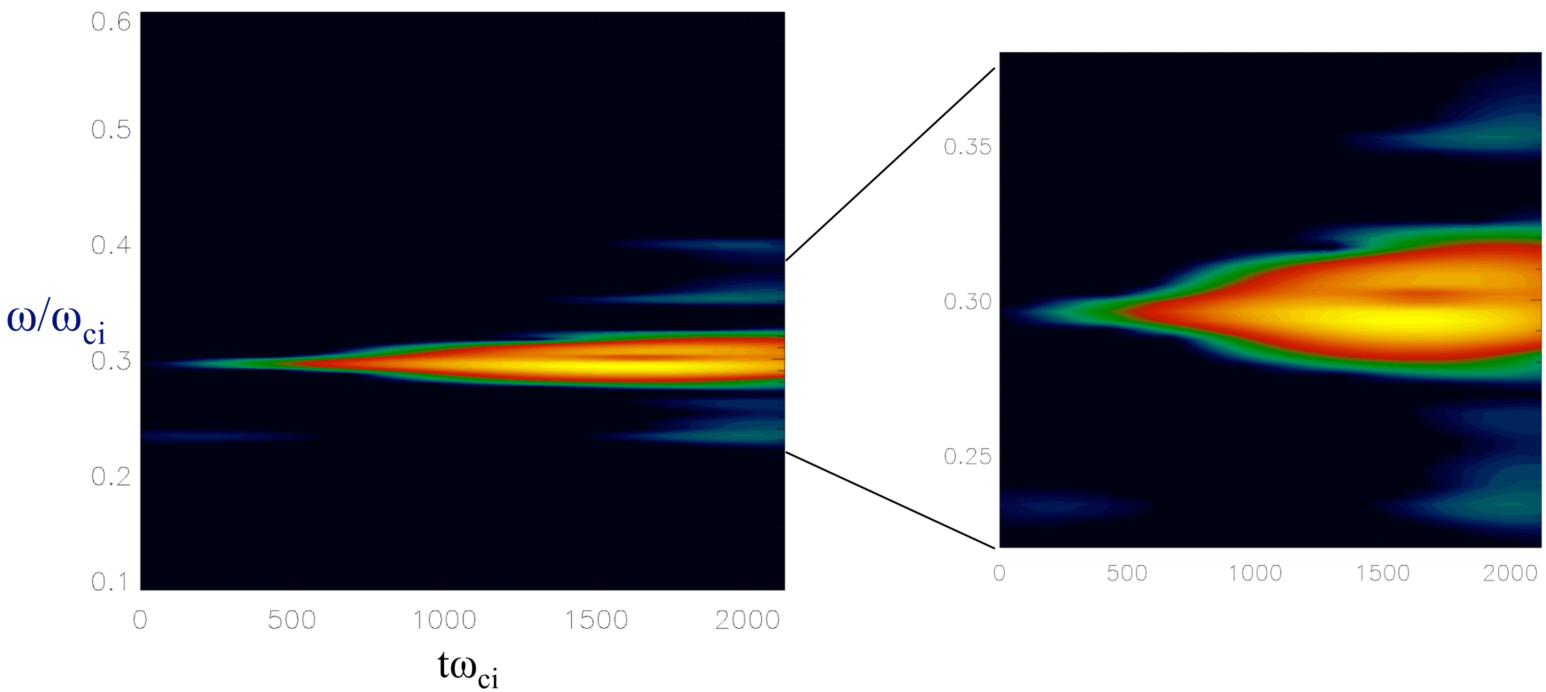
δP



δV_R

Frequency spectrum (case 4)

$\gamma_L = 0.0075\omega_{ci}$
$\gamma_d = 0.0033\omega_{ci}$



$2\Delta\omega \sim 0.015$
$\Delta\omega \sim \gamma_L$

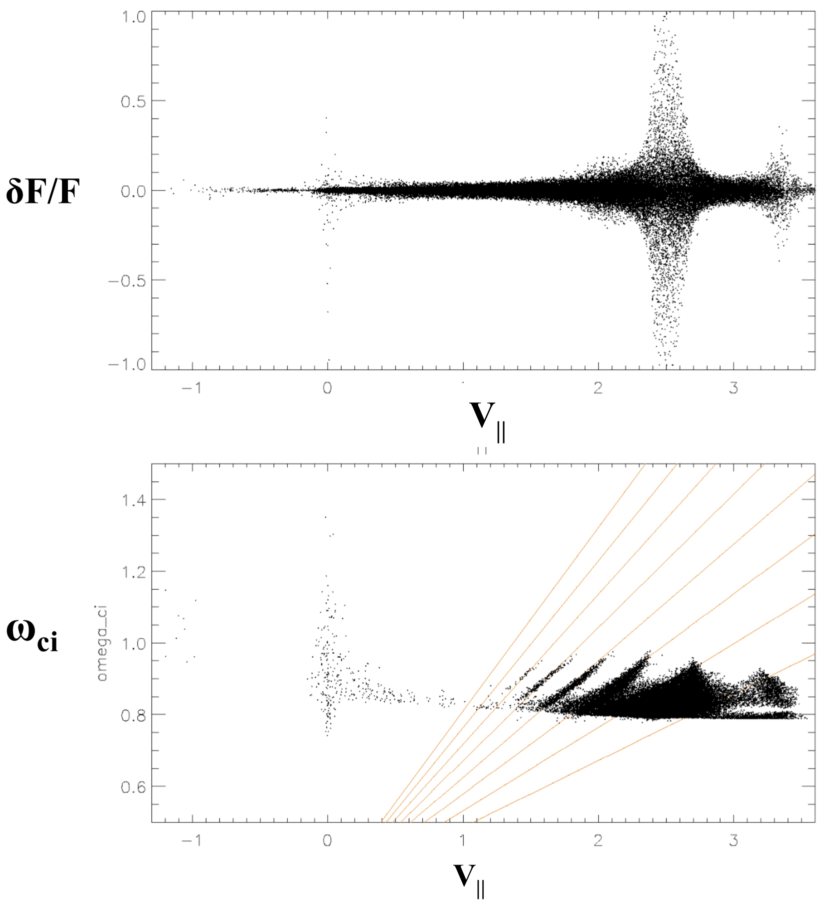
Time evolution of frequency spectrum from nonlinear simulations with $\gamma_d = 0.5\gamma_L$.

$$\Delta\omega = \pm 0.44\gamma_L \sqrt{t\gamma_d}$$ [Berk'97]

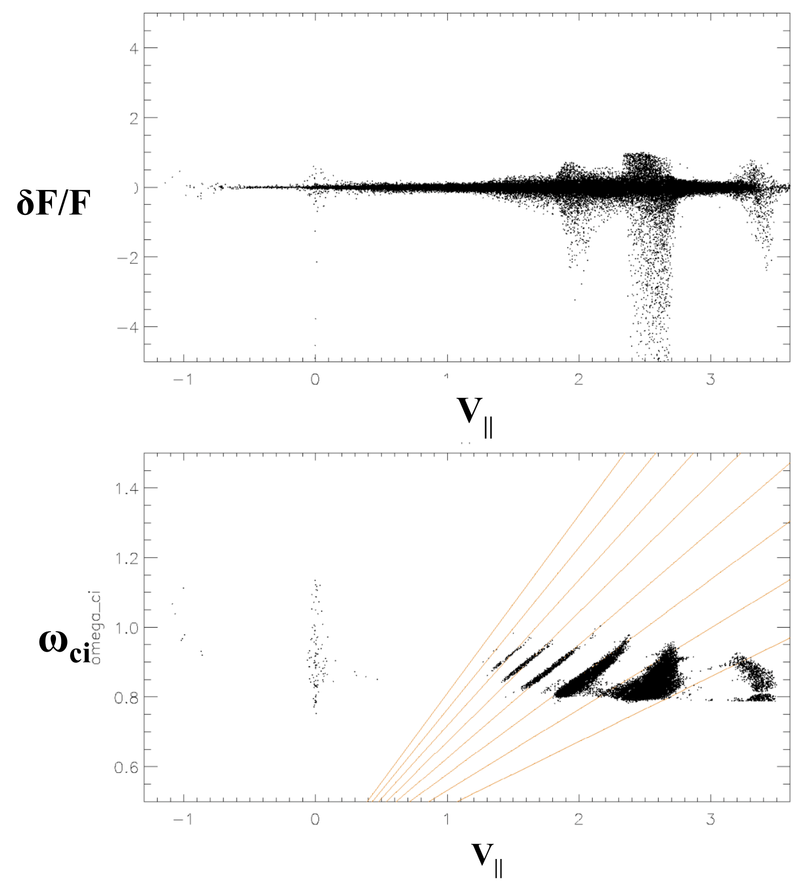
For $t\gamma_d \sim 3$, $\Delta\omega \sim 0.8\ \gamma_L$

Phase-space plots (case #3)

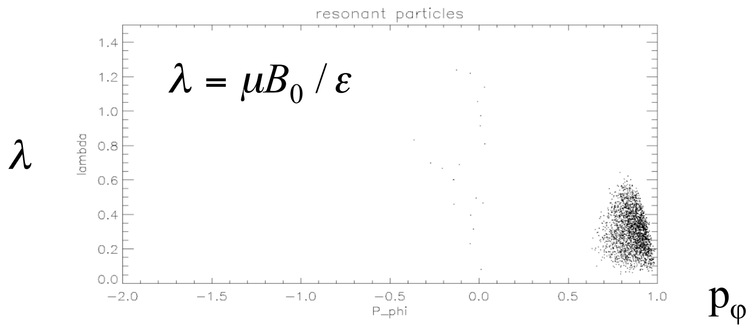
Linear



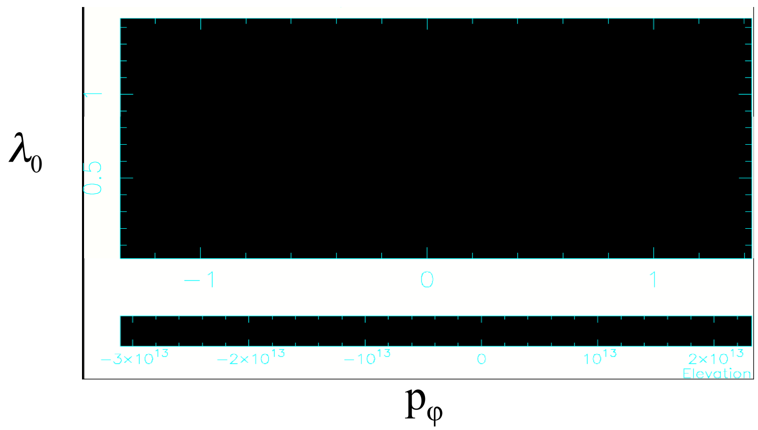
Nonlinear



More phase-space plots

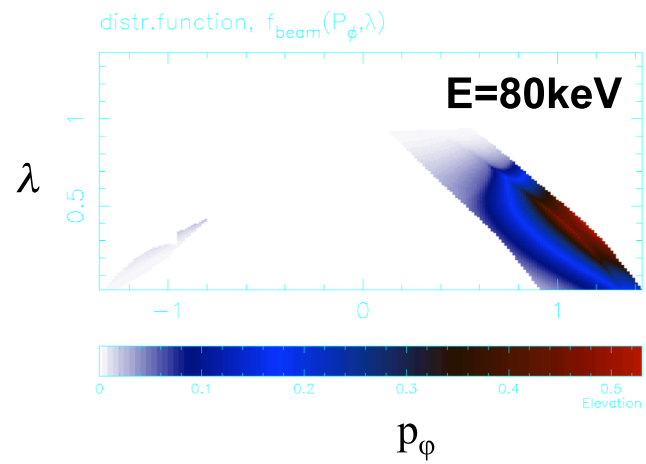


HYM (at saturation)



NOVA (linear)

Location of resonant regions in phase-space.



Equilibrium distribution for energetic ions.