Generation of RF-Driven Radial Current and Plasma Rotation in a Tokamak

Y.A. Omelchenko, V.S. Chan, Y.R. Lin-Liu and S.C. Chiu *

General Atomics
P.O. Box 85608, San Diego, California 92186-5608

41st APS Annual APS Meeting of the Division of Plasma Physics
Seattle, November 15-19, 1999

*The authors thank Roscoe White of PPPL for making his code ORBIT available for this work.

Abstract Submitted
for the DPP99 Meeting of
The American Physical Society

Sorting Category: 5.2 (Theoretical)

Generation of RF-Driven Radial Current and Plasma Rotation in a Tokamak[1] Y.A. OMELCHENKO, V.S. CHAN, Y.R. LIN-LIU, General Atomics, S.C. CHIU, Sunrise R&M, Inc. — Plasma rotation is potentially important for controlling the formation and positioning of internal transport barriers that could stabilize tokamak mictoturbulence and improve plasma confinement. This work focuses on identifying possible physical mechanisms capable of inducing plasma rotation and rotational shear via the ion cyclotron resonance frequency (ICRF) heating of minority ion species in a tokamak. Ion dynamics are calculated with a Monte-Carlo code in which wave-induced energy diffusion is accounted for by a quasilinear operator. The code follows particle drift trajectories in a tokamak geometry under the influence of RF fields and collisions with the background plasma. The effect of finite-size banana trajectories on resonance plasma heating and radial current generation are investigated and a conceptual model for the RF-induced toroidal plasma rotation is proposed. The results have been scaled with respect to the absorbed RF power and resonance position and are shown to be consistent with the magnitude of the toroidal rotation observed experimentally. Further development of the present RF model is discussed.

[1]Supported by U.S. DOE Grant DE-FG03-95ER54309.

☐ Prefer Oral Session
☒ Prefer Poster Session

Y.A. Omelchenko
omelche@gav.gat.com
General Atomics

Special instructions: immediately following SC Chiu

Date printed: July 15, 1999 Electronic form version 1.4

Simulation Setup

- We have conducted a series of hydrogen minority (D(H)) ICRH simulations for typical parameters of the Alcator C-Mod tokamak (see Table 1). The magnetic geometry is shown in Figs. 16,17. The toroidal magnetic field is in the co-current direction.

- The runs have been carried out with 20,000 test particles on a 50×50 (Ψ_p, θ)-grid (Table 2). To achieve a good resolution in the vicinity of the cyclotron resonance the particles are initialized in the radial range $r_{min} < r < r_{max}$ (not over the whole plasma cross-section).

- The RF antenna is assumed to emit a $k_{||}$-symmetric spectrum. A slightly peaked profile of the deposited RF power density was assumed, with $E_+ \sim (1 - r^2/a^2)^{\frac{1}{2}}$.

- The simulations have been carried out on a GA Beowulf cluster LUNA and typically required several hours to complete on 17 nodes.

GENERAL ATOMICS

Results

- The resonance ions form a distinct poloidal pattern consisting of the radially separated populations of particles (Figs. 18,19).
- The proton velocity distributions are highly anisotropic in $v_{||}$ even in the presence of an axisymmetric wave spectrum (Figs. 20,21). This confirms the importance of finite orbit effects.
- The collision induced radial diffusion remains at least by an order of magnitude smaller compared to the pure RF-driven transport.
- The regions of inward and outward directed radial flows are well separated (Figs. 22,23). The temporal evolution of the resonant ion density is consistent with generated radial flows (Figs. 24,25).
- The estimates and scaling of the central rotation velocity as a function of resonance position (Table 2) are in good agreementwith experimental observations of the co-current plasma rotation in H-mode discharges with no direct momentum input (Fig. 11).

Table 1 (Alcator C-Mode)

H/D Density Ratio, n_H/n_D	0.05
Major Radius, R_0	67 cm
Minor Radius, a	22 cm
Background B	5.3 T
RF Power, P_{rf}	2 MW
RF Wave Frequency, ν_{rf}	80 MHz
RF Wave Number, $n_{\|\|}$	21
Plasma Density, n_e	3×10^{14} cm^{-3}
Ion Temperature, T_i	5 keV
Electron Temperature, T_e	2 keV
Slowing-down Time, $\tau_s = 1/\nu_{\|\|}$	0.01 sec
Confinement Time, τ_E	0.05 sec
Maximum Safety Factor, $q(r = a)$	4

Table 2 (Run Summary)

Minimum radius, r_{min}/a	**0.1**	**0.3**
Maxium radius, r_{max}/a	**0.6**	**0.9**
Resonance Position, r_{res}/a	**0.36**	**0.66**
Resonance Width, $\Delta r/a$	**0.15**	**0.1**
Radial Flow Velocity, v_r^{rf} $(10^3\ \mathrm{cm/sec})$	**5.0**	**3.0**
Run time (τ_s)	**2.6**	**2.6**
Rotation Velocity, $v_\zeta(0)$ **(km/sec)**	**210**	**70**

Figure 1: Magnetic Field Profiles

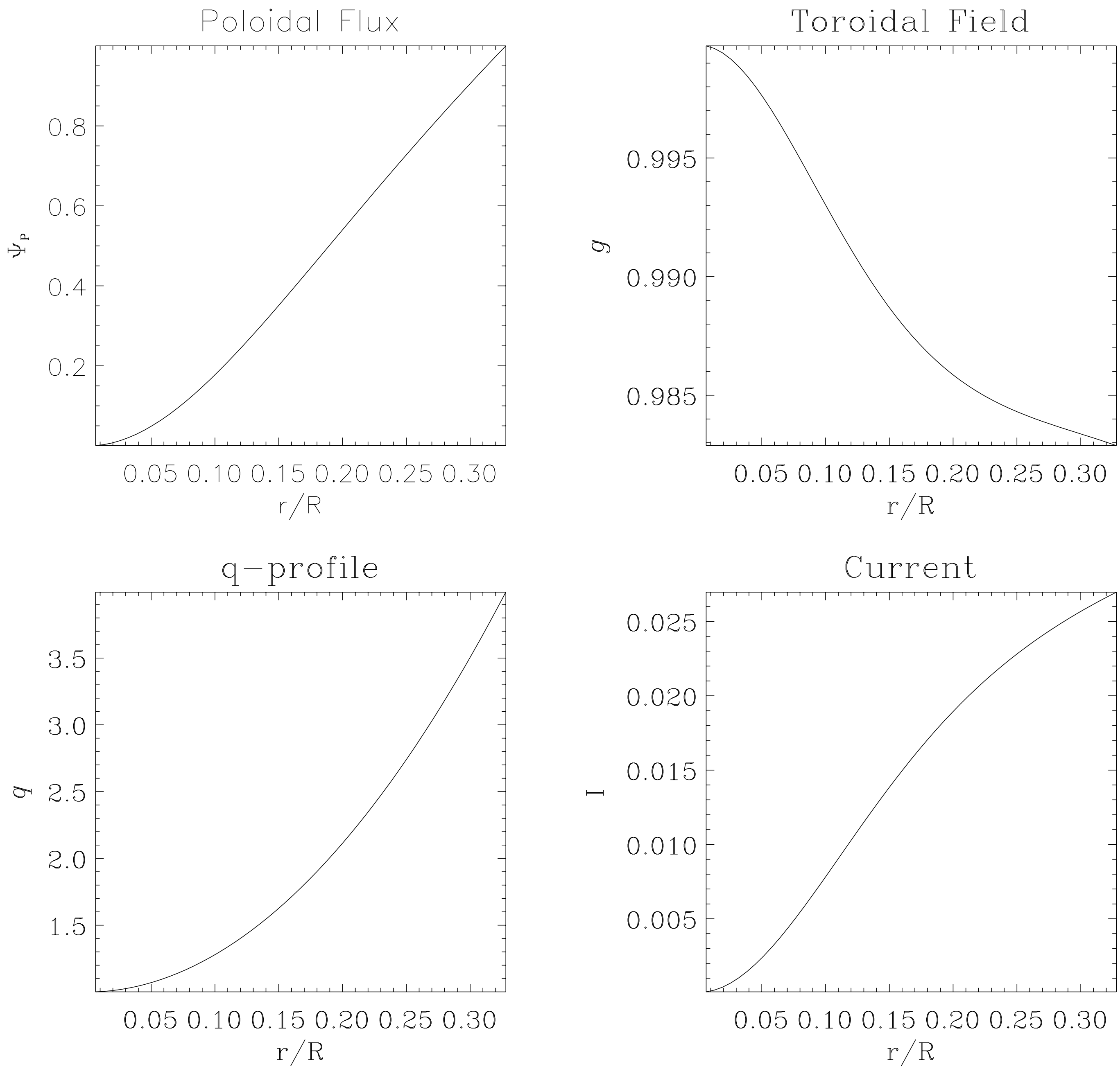


Figure 2: Magnetic Field Topology

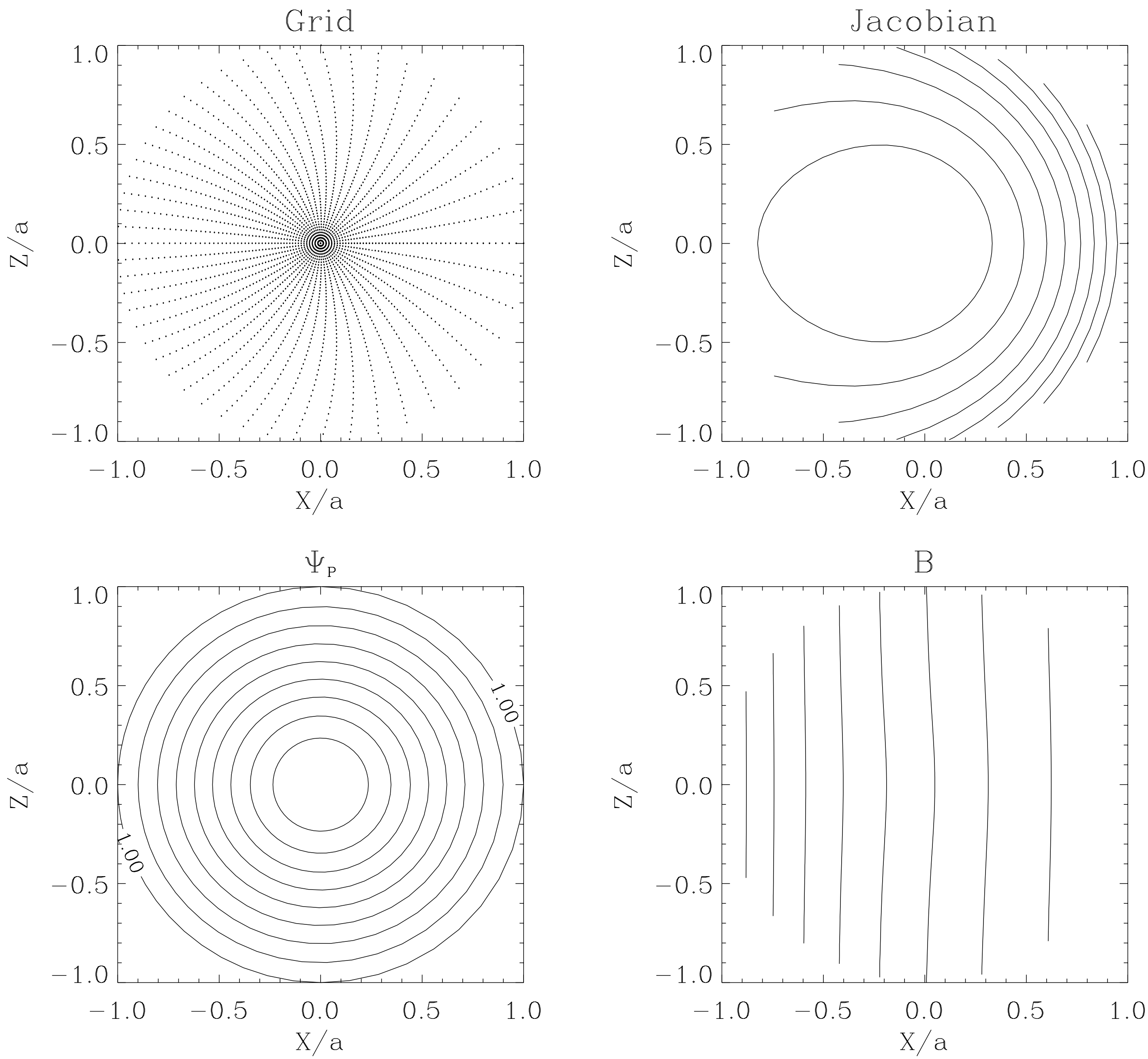


Figure 3: ICRH in Configuration Space ($r_{res}/a = 0.36$)

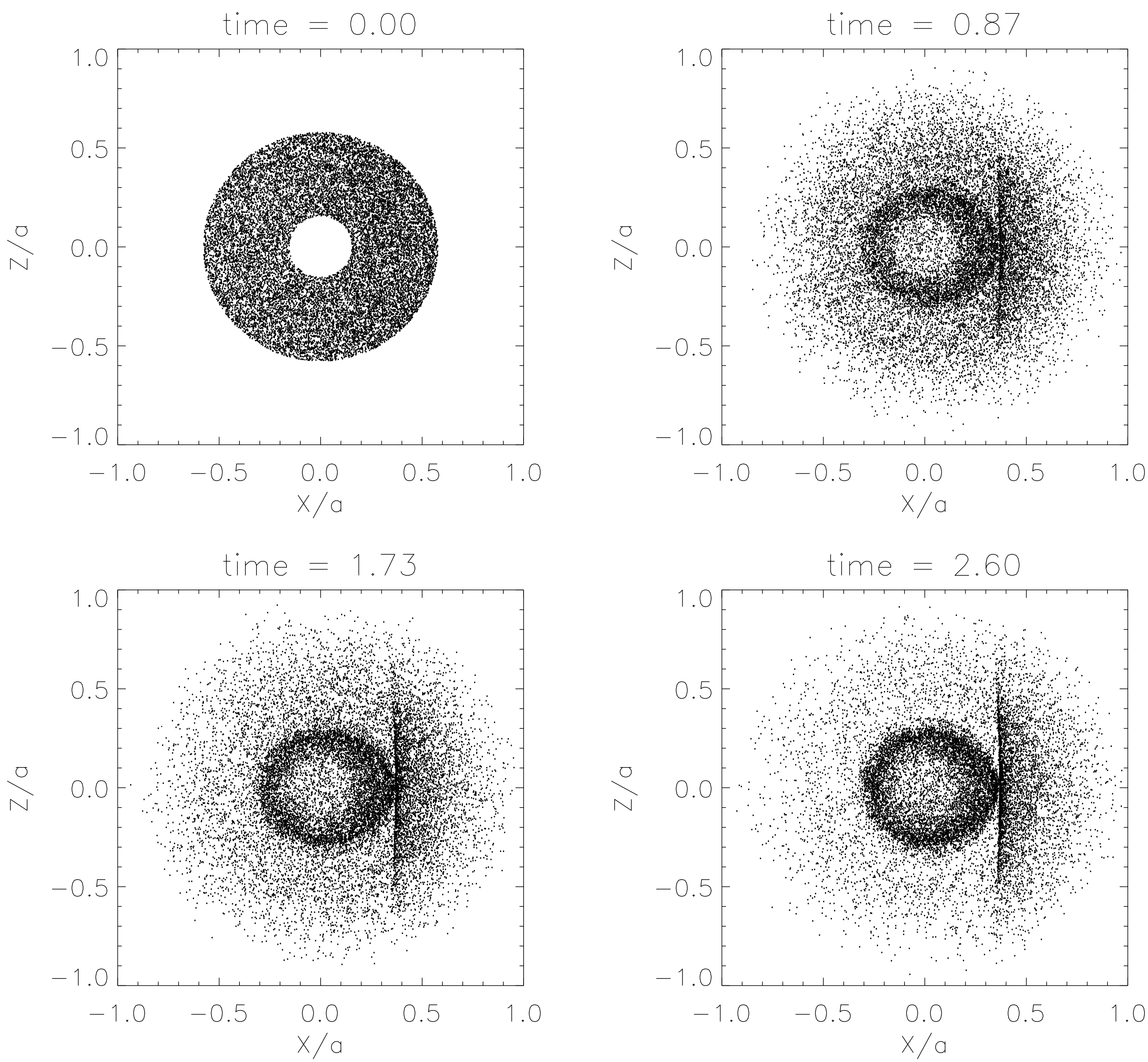


Figure 4: ICRH in Configuration Space ($r_{res}/a = 0.66$)

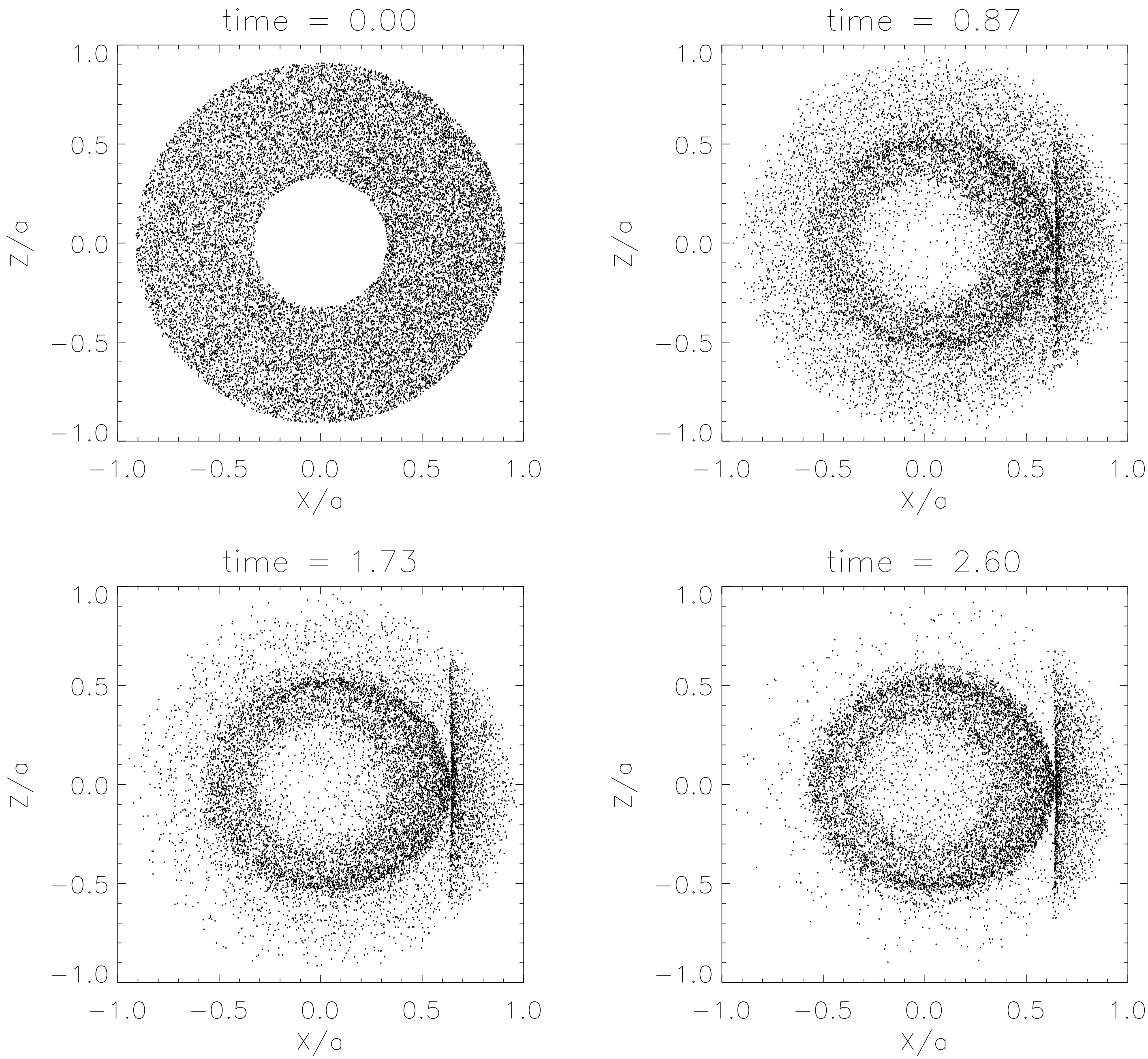


Figure 5: ICRH in Velocity Space ($r_{res}/a = 0.36$)

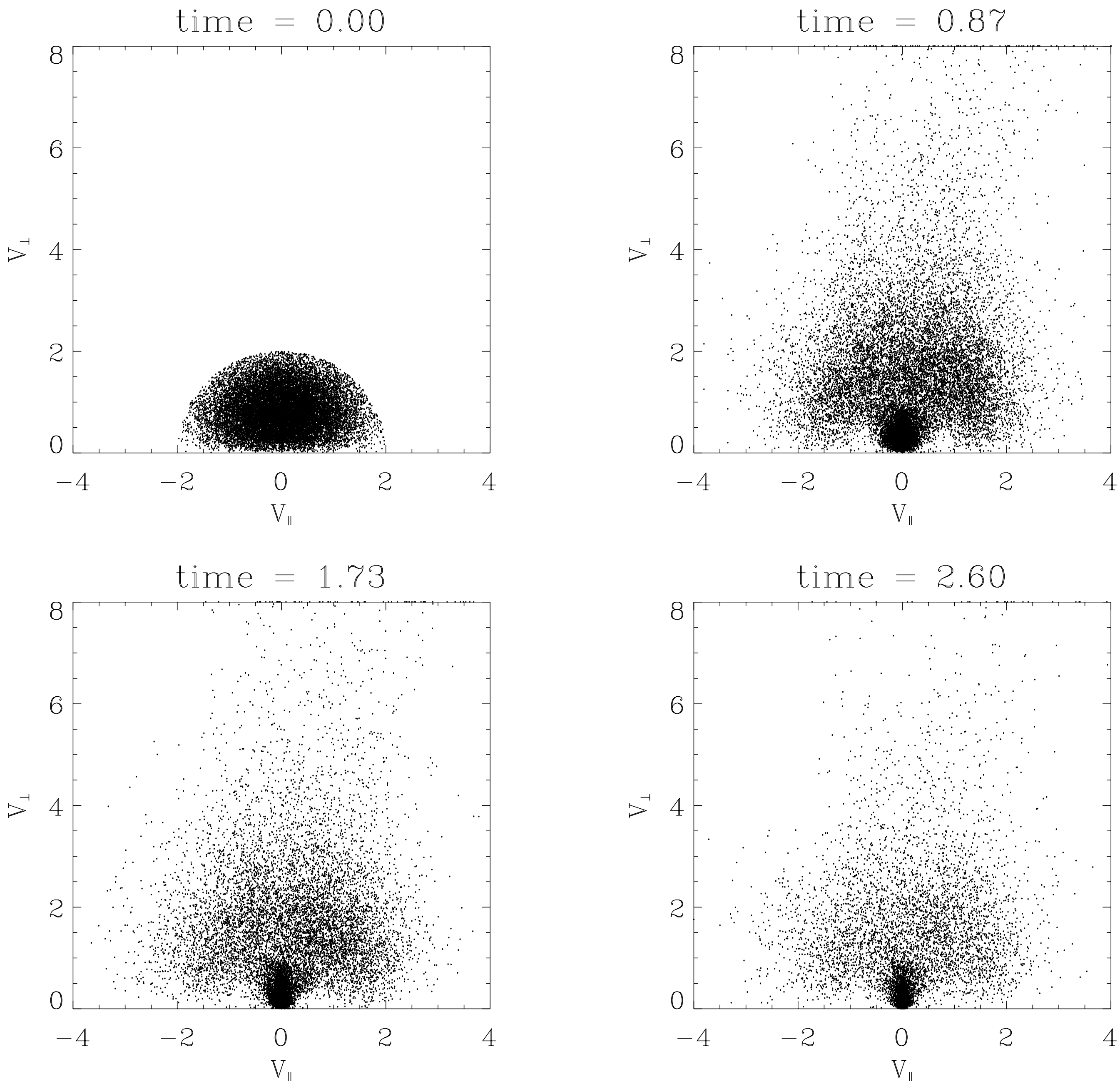


Figure 6: ICRH in Velocity Space ($r_{res}/a = 0.66$)

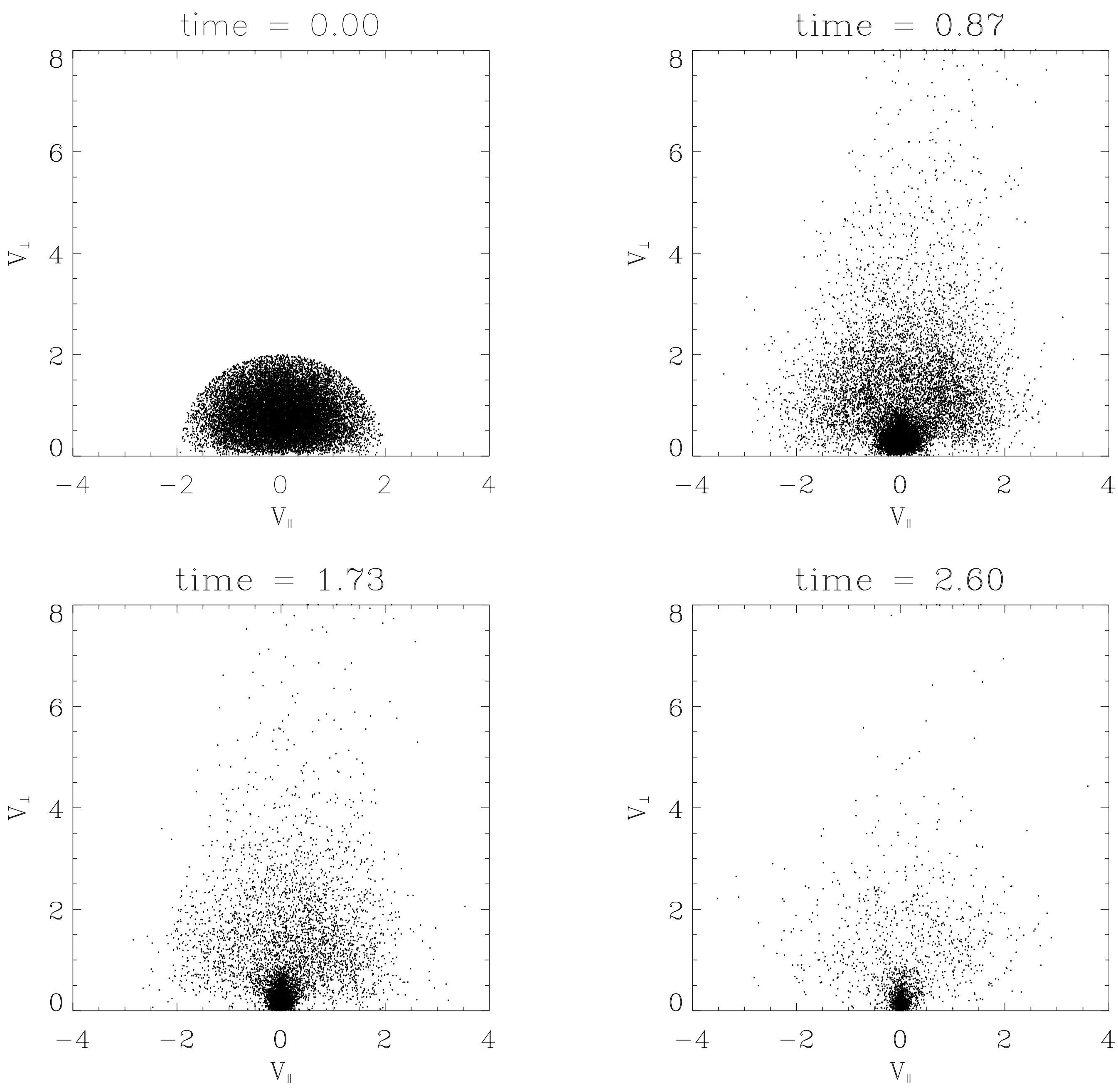


Figure 7: Resonant Ion Flow Profile ($r_{res}/a = 0.36$)

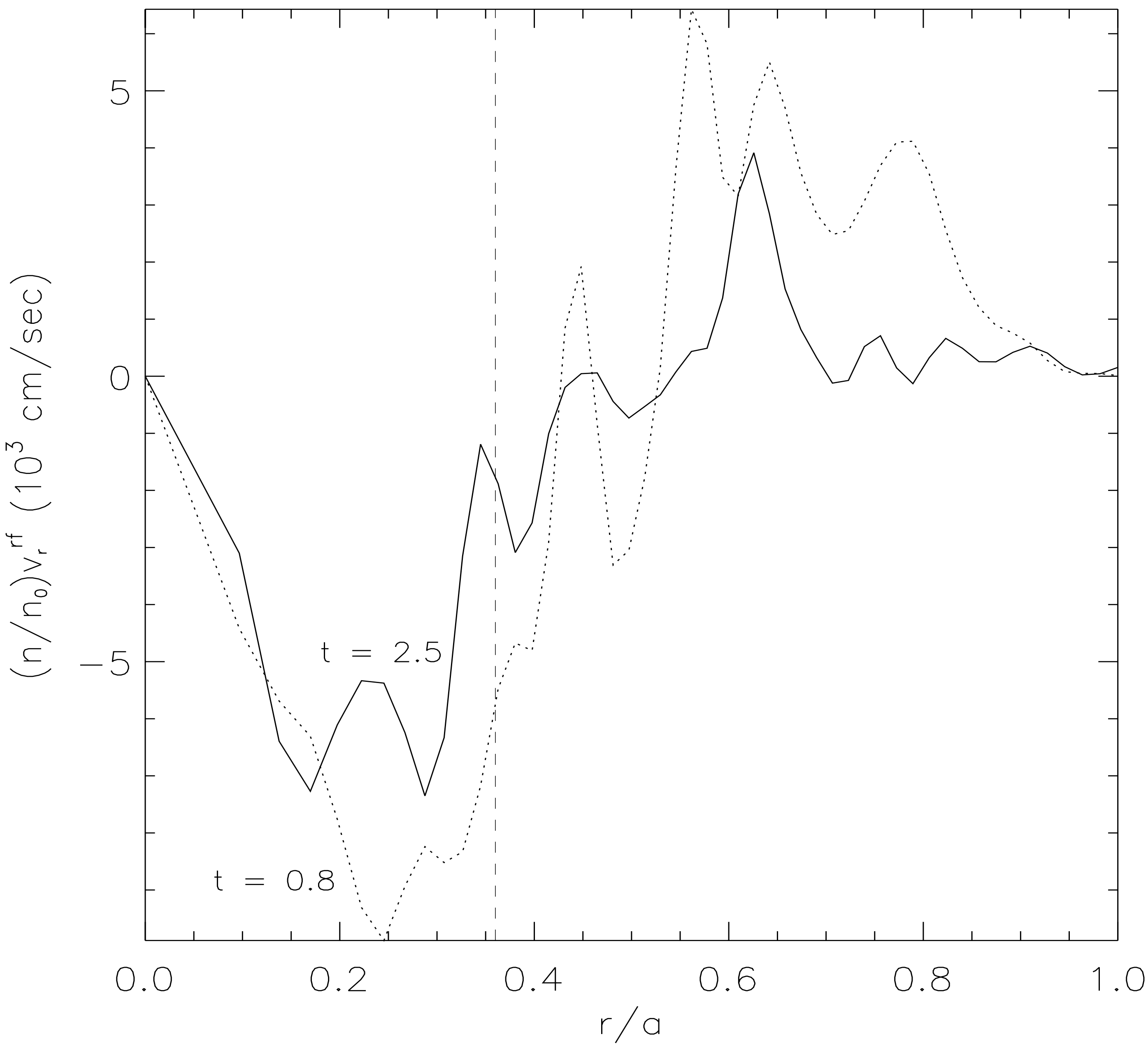


Figure 8: Resonant Ion Flow Profile ($r_{res}/a = 0.66$)

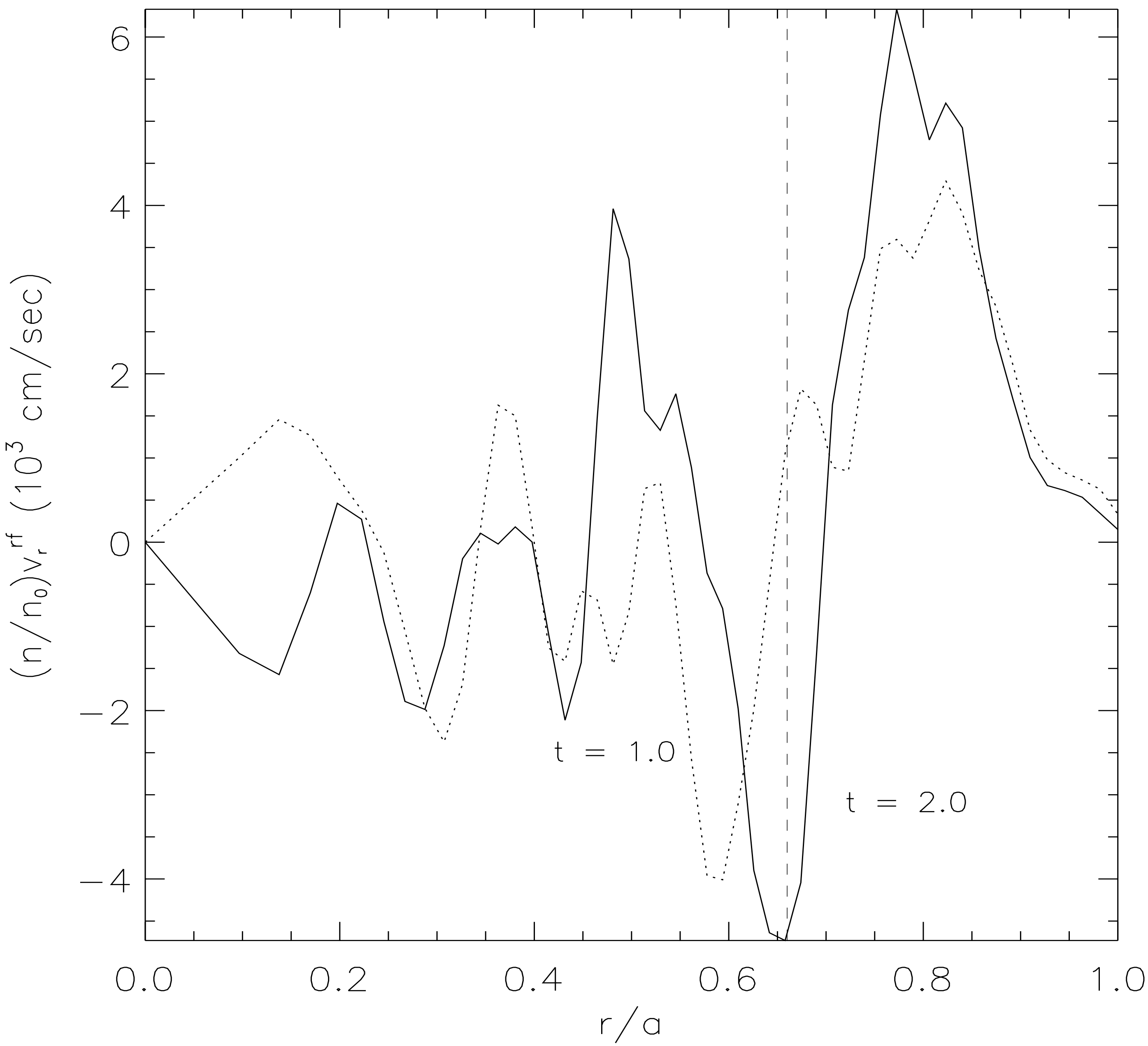


Figure 9: Resonant Ion Density Profile ($r_{res}/a = 0.36$)

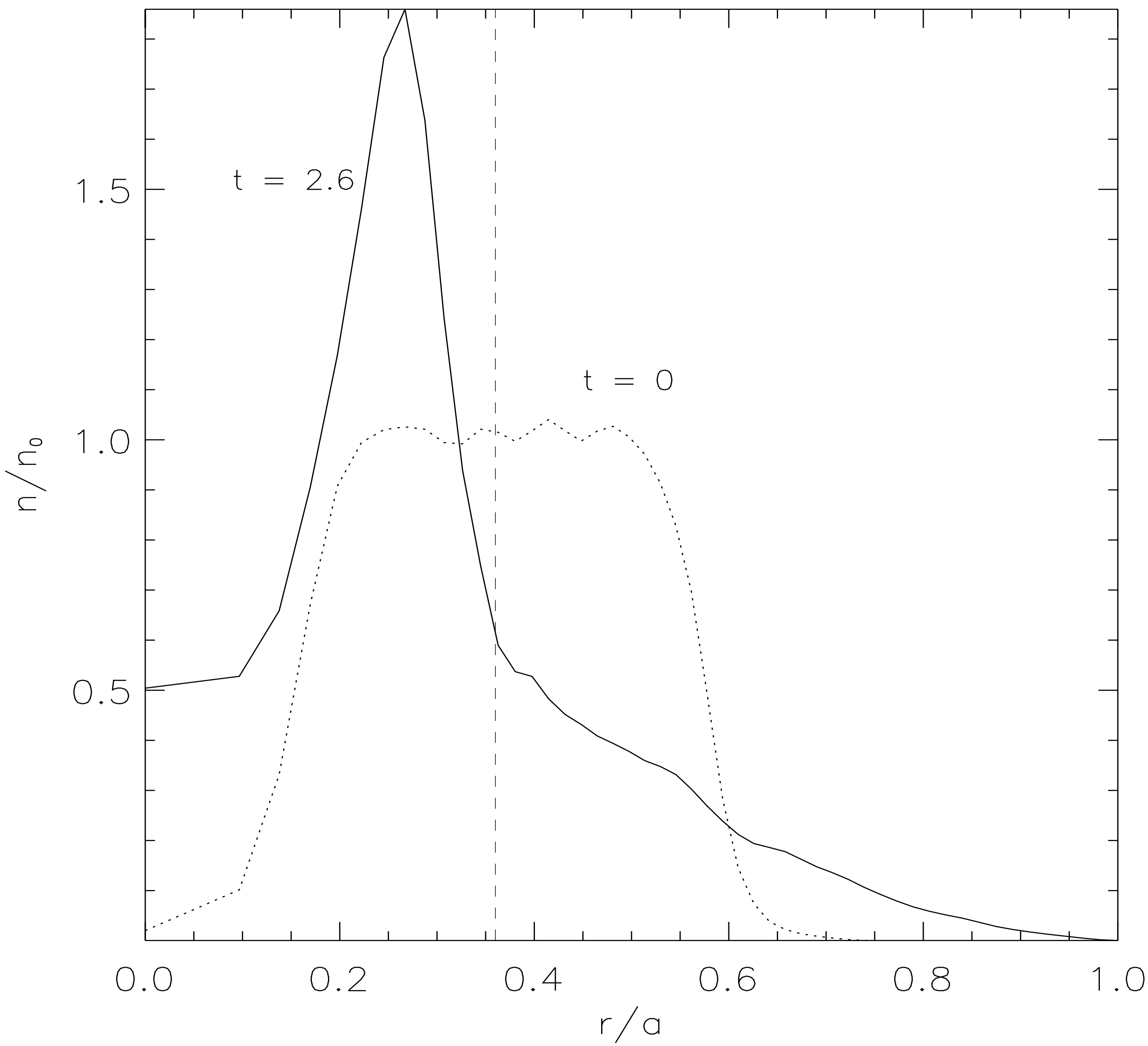
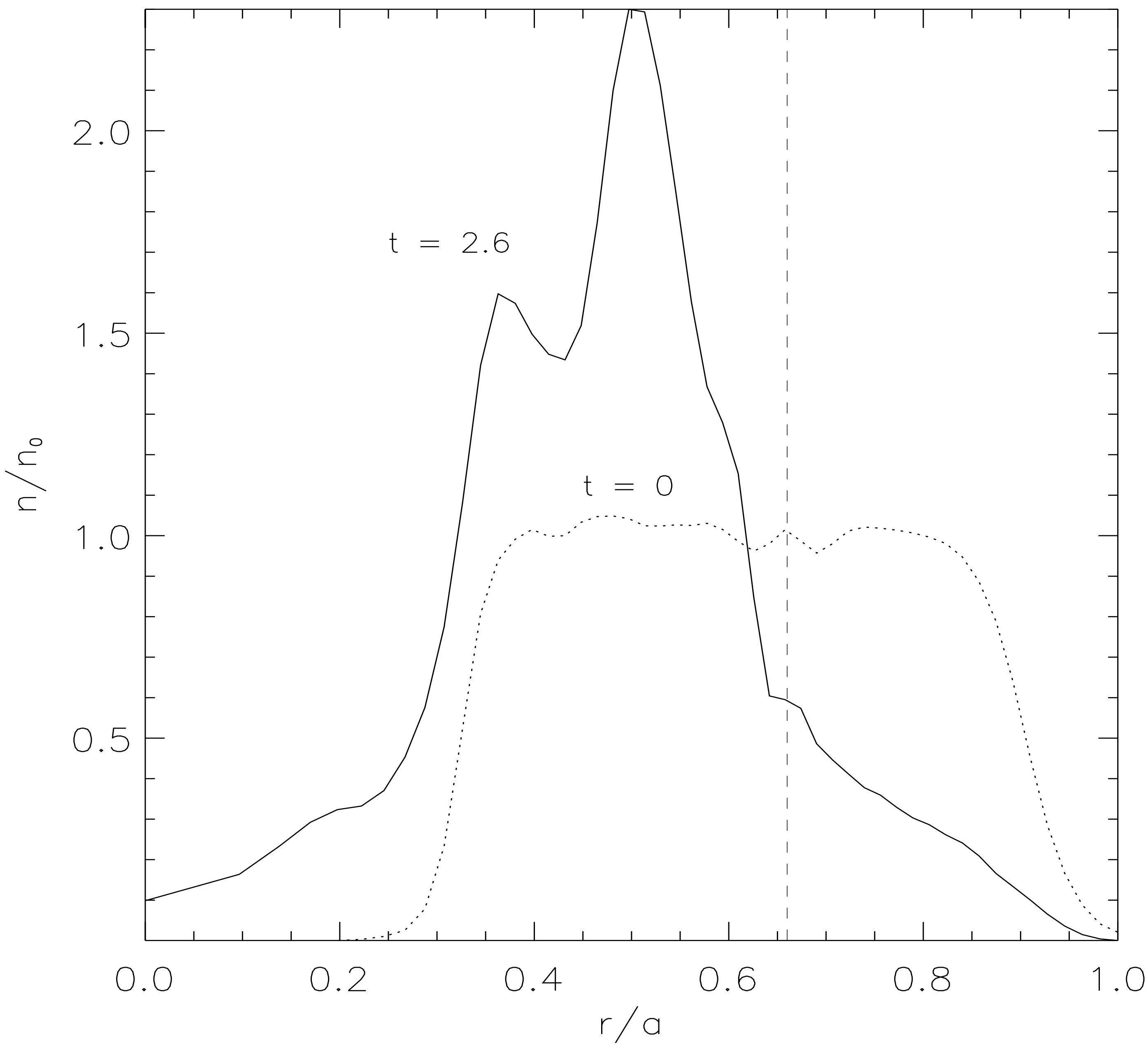


Figure 10: Resonant Ion Density Profile ($r_{res}/a = 0.66$)



References

[1] K. Ida, Plasma Phys. Contr. Fusion **10**, 1429 (1998).

[2] M. Mattioli et al., J. Appl. Phys. **64**, 3345 (1988).

[3] L.-G. Eriksson, E. Righi, and K.-D. Zastrow, Plasma Phys. Contr. Fusion **39**, 27 (1997).

[4] J.E. Rice et al., Nucl. Fusion **38**, 75 (1998).

[5] M.N. Rosenbluth and F.L. Hinton, Nucl. Fusion **36**, 55 (1996).

[6] C.S. Chang et al. In *Proc. of the 17th International Sherwood Fusion Theory Conference*, 1998. Atlanta, Georgia, Paper 2B1.

[7] F.W. Perkins and R.B. White. In *Proc. of this conference*, 1999.

[8] B. Coppi and G. Penn. "Theoretical Model of Plasma Rotation Paradox". In *Proc. of the 17th International Conference on Plasma Physics and Controlled Fusion*, 1998. Yokohama, IAEA-F1-CN-69/TH3/7.

[9] R.B. White and A.H. Boozer, Phys. Plasmas **2**, 2915 (1995).

[10] S.C. Chiu et al.submitted to Phys. Plasmas (1999).

[11] T.H. Stix, Nucl. Fusion **15**, 737 (1975).

[12] A.H. Boozer and G. Kuo-Petravic, Phys. Fluids **24**, 851 (1981).

[13] W.G.F. Core, Nucl. Fusion **29**, 1101 (1989).

[14] M.A. Kovanen, W.G.F. Core, and T. Hellsten, Nucl. Fusion **32**, 787 (1992).