# Transport simulation using extended transport model

M. Yagi, A. Tsukamoto*, S.-I. Itoh
RIAM, Kyushu Univ.
*IGSES, Kyushu Univ.

# INTRODUCTION

- **Objective**
  - To analyze intermittent transport on plasma edge
  - Incorporate probabilistic view into model
- **In this talk**
  - □ Derivation of extended transport model
  - □ Transport simulation using simple ITG model
  - □ Future work

# L-H Transition model

## Nonambipolar flux model (Ginzburg-Landau)

S.-I. Itoh, K. Itoh,and A. Fukuyama, NF 33 1445(1993).

$$\left(1+\frac{c^2}{v_A^2}\right)\varepsilon_0 \frac{dE_r}{dt} = -e(\Gamma_i^{NA}(E_r) - \Gamma_e^{NA}(E_r)) + \frac{e\rho_p n_i}{B_p v_{Ti}} \mu_i \frac{\partial^2}{\partial x^2} E_r$$

## Self-regulating shear flow turbulence model (Predator-prey)

P.H. Diamond, Y.-M. Liang, B.A. Carreras and P.W. Terry, PRL 72 2565(1994).

$$\frac{1}{2}\frac{dE}{dt} = \gamma_0 E - \alpha_1 E^2 - \alpha_2 UE$$

$$\frac{1}{2}\frac{dU}{dt} = -\mu U + \alpha_3 UE$$

# Transport model based on Reduced MHD

- Solve poloidal flow and ion temperature
- Assume electron response is adiabatic

**Momentum loss** →

- **Ion loss cone loss**
- **Ion bulk viscosity**

**Anomalous transport** →

**ITG mode**

**Mixing length fomula**
**(only coherent part)**

## ■Vorticity equation

$$n_0 m_i\left(\frac{\partial}{\partial t}\nabla_\perp^2 F + \left[F,\nabla_\perp^2 F\right]\right) - \frac{1}{\Omega_i}\nabla_\perp\cdot\left[p_i,\nabla_\perp F\right]$$

$$= \frac{B_0}{c}\nabla_\parallel J_\parallel + e n_0\frac{B_0}{c}\nabla F\times\nabla\Omega\cdot\hat{z} + \mu\nabla_\perp^4 F + \frac{B_0}{c}\frac{d}{dr}J^r$$

with $F = \frac{c}{B_0}\left(\phi + \frac{1}{e n_0}p_i\right)$ $\quad p_i = n_0 T_i + \frac{e n_0}{T_{e0}}T_{i0}\phi$

## ■Parallel momentum balance

$$n_0 m_i\left(\frac{\partial \upsilon_\parallel}{\partial t} + \frac{c}{B_0}\left[\phi,\upsilon_\parallel\right]\right) = -e n_0\nabla_\parallel F + 4\mu\nabla_\perp^2\upsilon_\parallel$$

## ■Ion temperature evolution

$$\frac{3}{2}n_0\left(\frac{\partial T_i}{\partial t} + \frac{c}{B_0}\left[\phi,T_i\right]\right) - T_{i0}\left(\frac{\partial n}{\partial t} + \frac{c}{B_0}\left[\phi,n\right]\right) = -\nabla_\parallel q_\parallel + \kappa_\perp\nabla_\perp^2 T_i + S$$

- Flux surface average of eqs.(1) and (3).
- For simplicity, eq.(2) is decoupled.

$$r/a \to \hat{r}, v_{T_{i0}}/at \to \hat{t}, \chi/av_{T_{i0}} \to \hat{\chi}, Sa/v_{T_{i0}} \to \hat{S}$$

$$v^{bv} = \Gamma^{bv}/n_{i0}, v^{lc} = \Gamma^{lc}/n_{i0}$$

$$\frac{\partial}{\partial \hat{t}} U_p = \frac{a}{\rho_{i0}} \left( \underline{v^{bl} + v^{lc}} \right) + \hat{\chi}^{ITG} \frac{\partial^2}{\partial \hat{r}^2} U_p + \hat{\chi}_c \frac{\partial^2}{\partial \hat{r}^2} U_p$$

$$\frac{3}{2} \frac{\partial}{\partial \hat{t}} T_i = \hat{\chi}^{ITG} \frac{\partial^2}{\partial \hat{r}^2} T_i + \hat{S} + \hat{\chi}_c \frac{\partial^2}{\partial \hat{r}^2} T_i + \hat{\chi}^{NC} \frac{\partial^2}{\partial \hat{r}^2} T$$

$$\hat{\chi}^{ITG} = \hat{\chi}^{ITG}(U_p, T_i)$$

**NC:**

F.Hinton and R.Hazeltine, Rev.Mod.Phys. 48,no2,Part1

K.C. Shaing et al., PF B2 1492(1989).

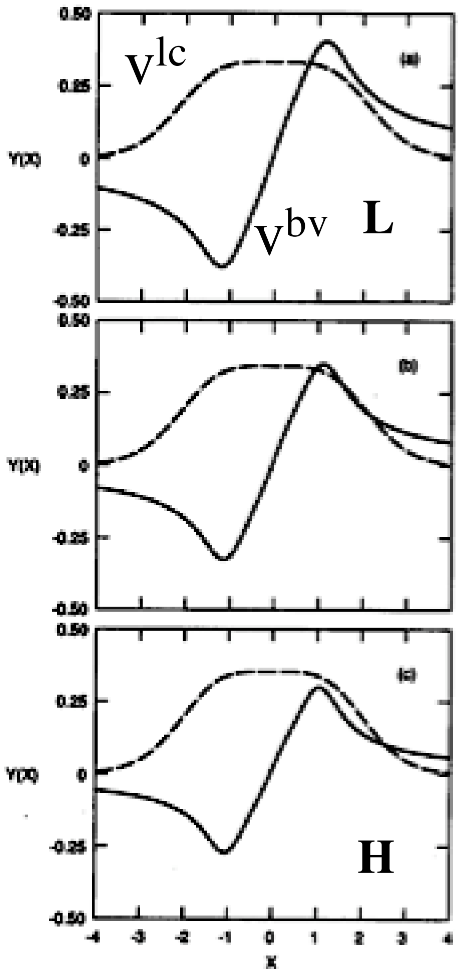



FIG. 2. The transition of $U_{p,m} \equiv X$ from (a) the L root to (b) the multiple-root state and finally to (c) the H root as $\nu_{ai}$ decreases from 2.3 in (a) to 1.7 in (c). The dashed lines are $Y_1(X)$, and the solid lines are $Y_2(X)$.

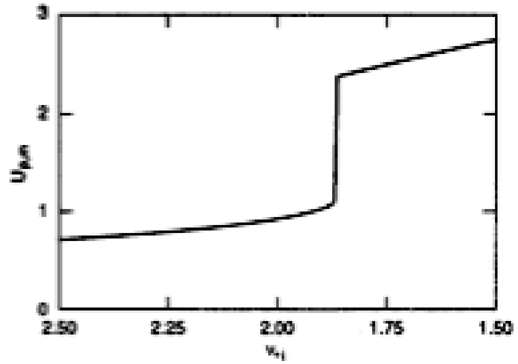



FIG. 3. The change of $U_{p,m}$ as $\nu_{ai}$ decreases.

# Transport Coefficient

$$\chi^{ITG}(U_p, T_i) = \frac{\gamma^{ITG}}{k_\perp^2}(1 - \Omega^2)$$

$$\Omega = \frac{k_\theta \upsilon'_{E\times B} W_k}{\gamma^{ITG}} \quad , W_k \approx \frac{1}{k_y} \approx 5\rho_i$$

$$\gamma^{ITG} = \frac{k_y \rho_i \upsilon_{Ti}}{L_n} \varepsilon_n^{1/2} \sqrt{\eta_i - \eta_{ic}}$$


P.H.Diamond et al., PP 1 4014(1994).

F.Romanelli, PF B 1 1018(1989).

A. Fukuyama et al., PPCF 38 1319(1996).

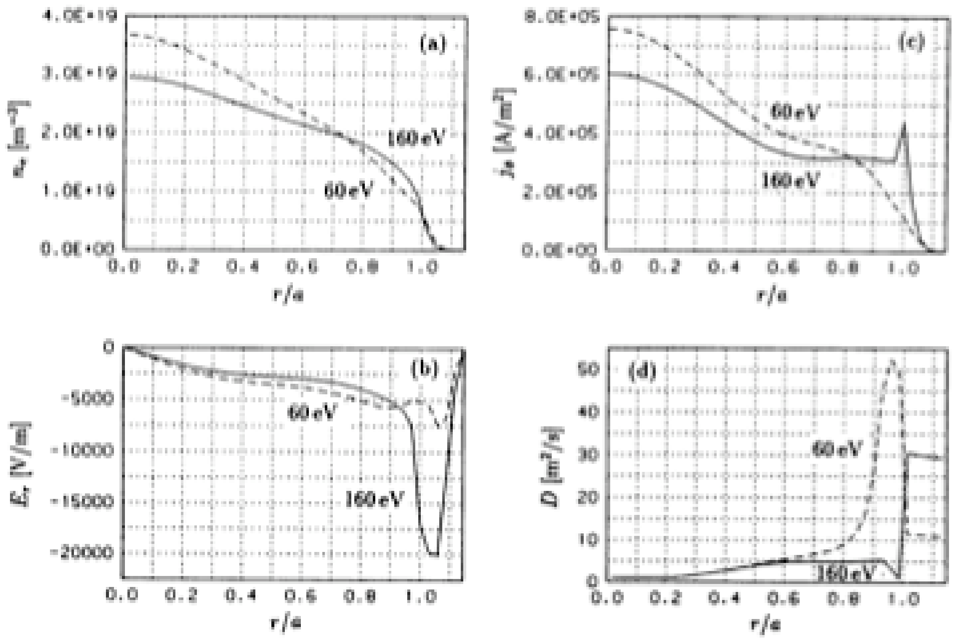



**Figure 1.** Profiles of the density (a), the radial electric field (b), the current density (c) and the diffusion coefficient (d). The dashed curves denote the case $T_{edge} = 60$ eV and the full curves 160 eV.

**$E_r$ formation depends on edge temperature.**

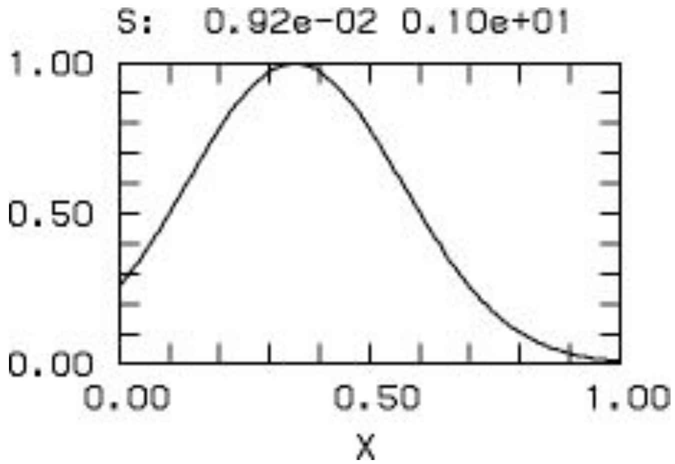
# CASE1

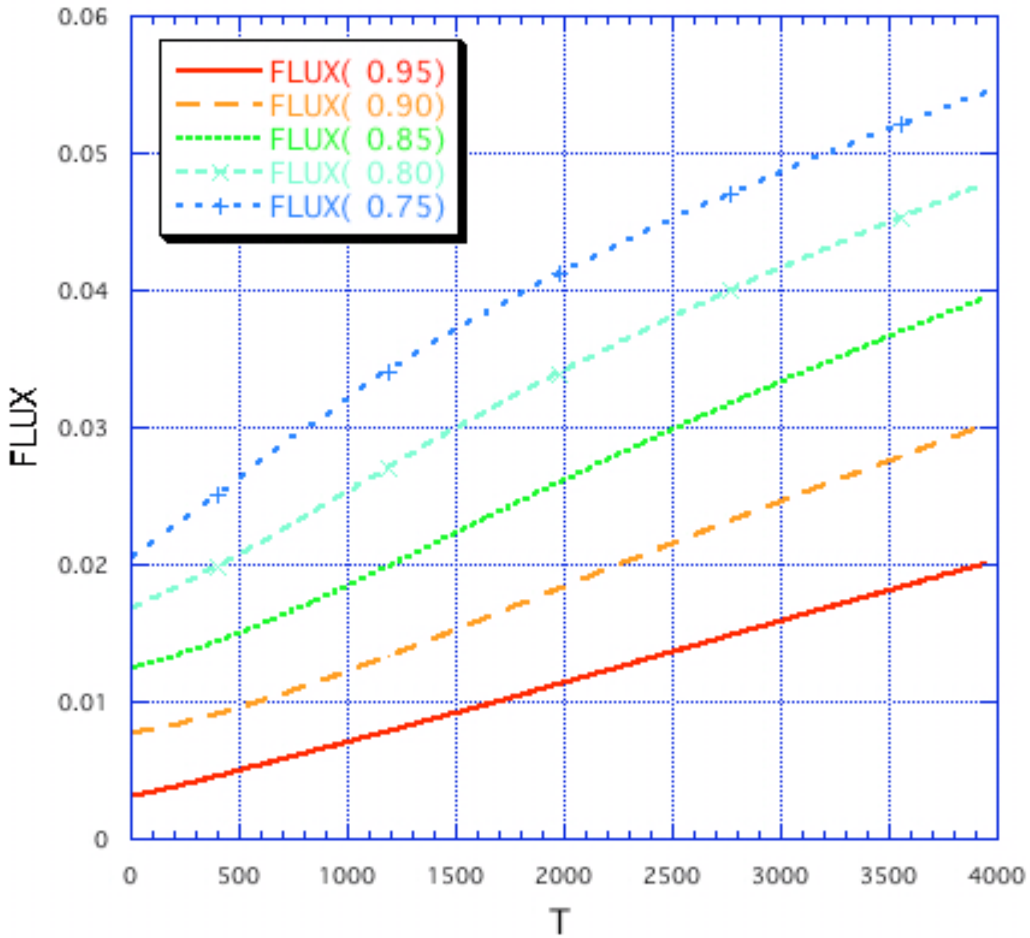
Initial profile

Source term $S = S_0 \exp\{-(r - r_s)^2 / \sigma\}$

$$T_i(r) = T_{i0}(1 - r^2)^2 + T_{i1}$$

$$T_{i1} = 200 eV$$



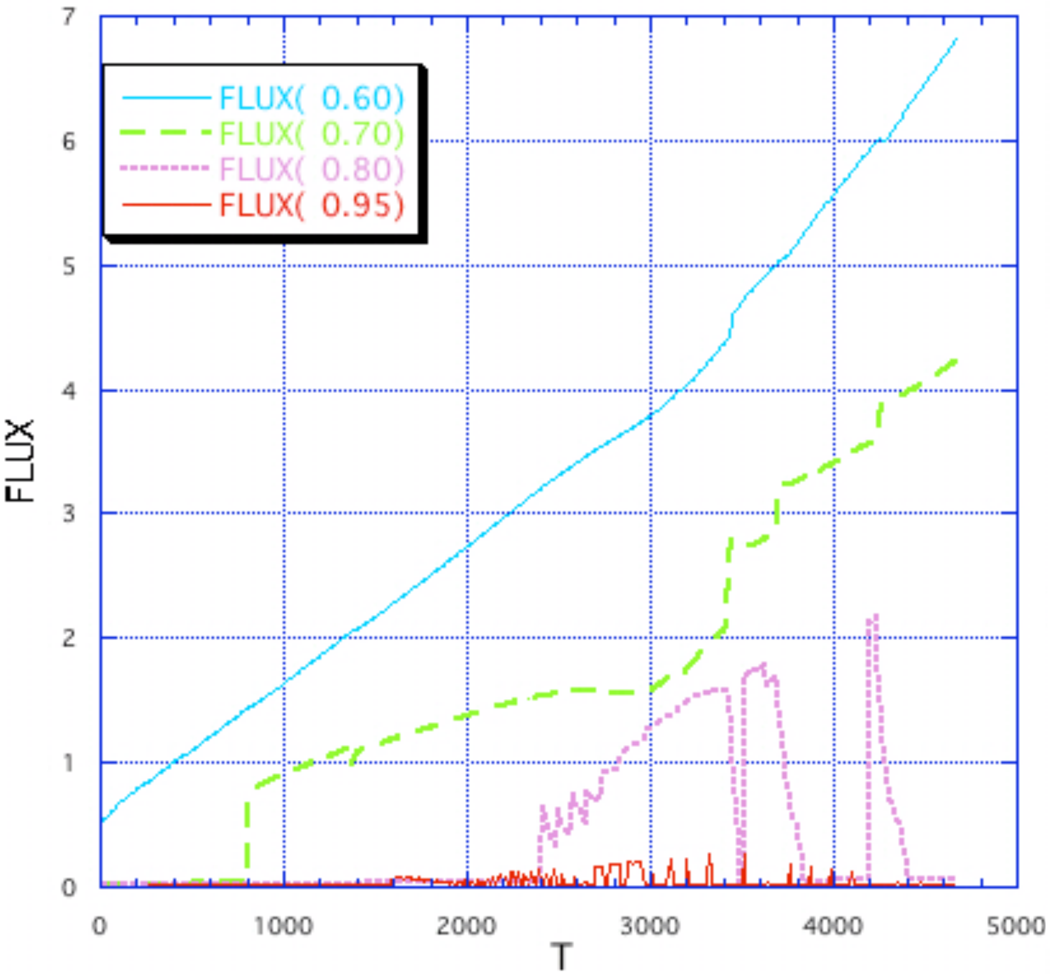



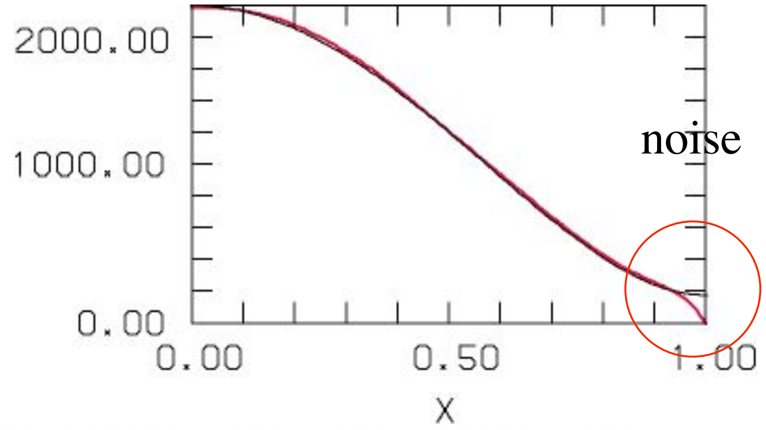

Boundary Condition

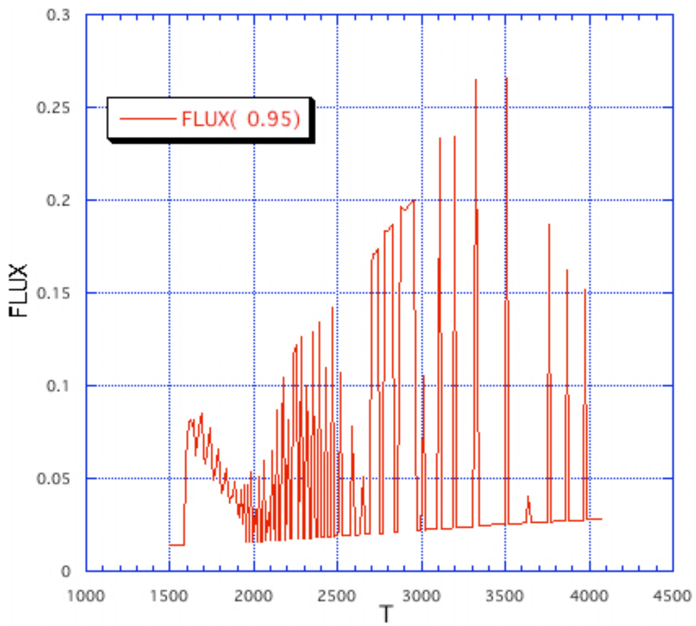
$$\begin{cases} \dfrac{\partial T_i}{\partial r}(r=0) = 0 \\ T_i(r=1) = \underline{TI1} \\ U_p(r=0) = 0 \\ \dfrac{\partial^2 U_p}{\partial r^2}(r=1) = 0 \end{cases}$$

# CASE2: Same as CASE 1 except B.C.

B.C. $T_i(1) = 0$

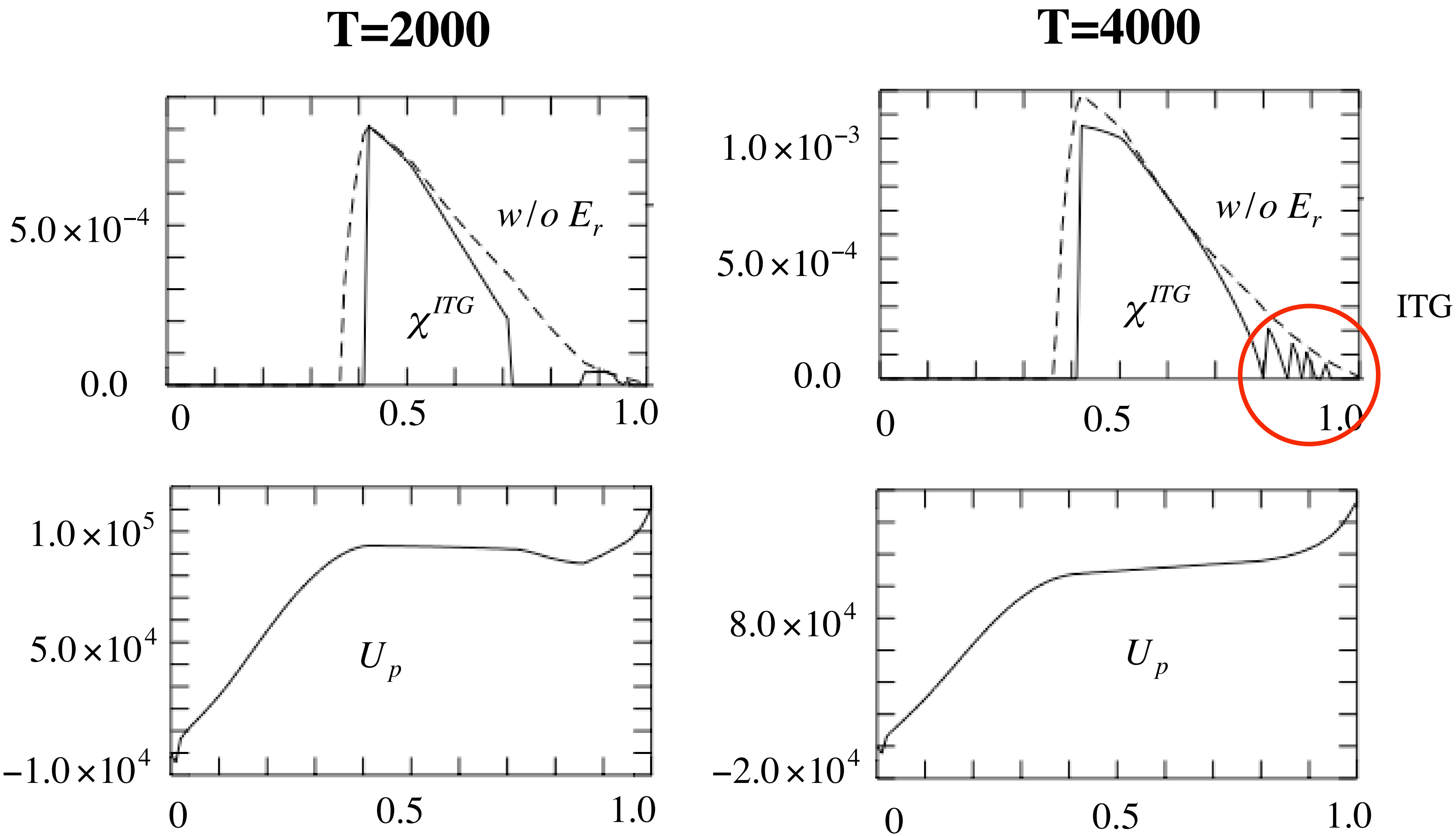


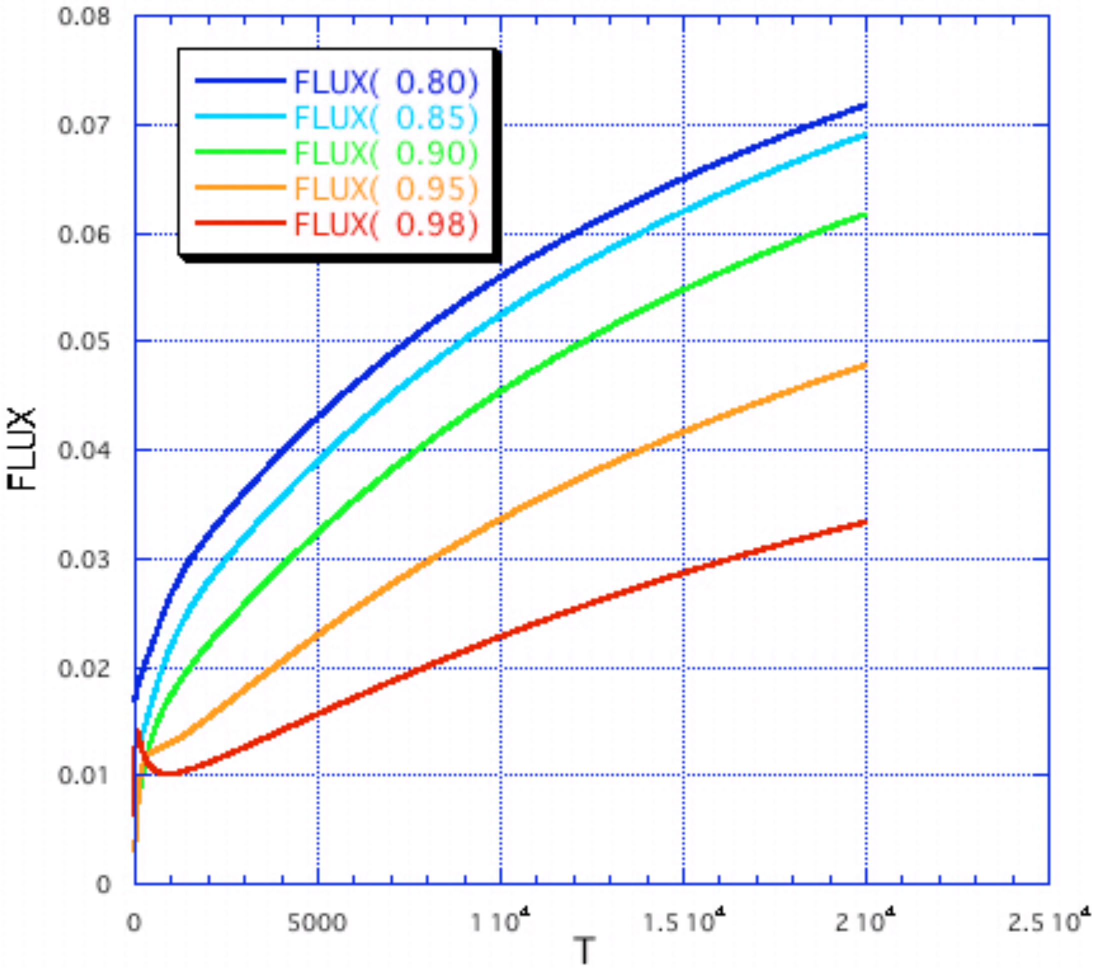

extended

# Profile Evolution

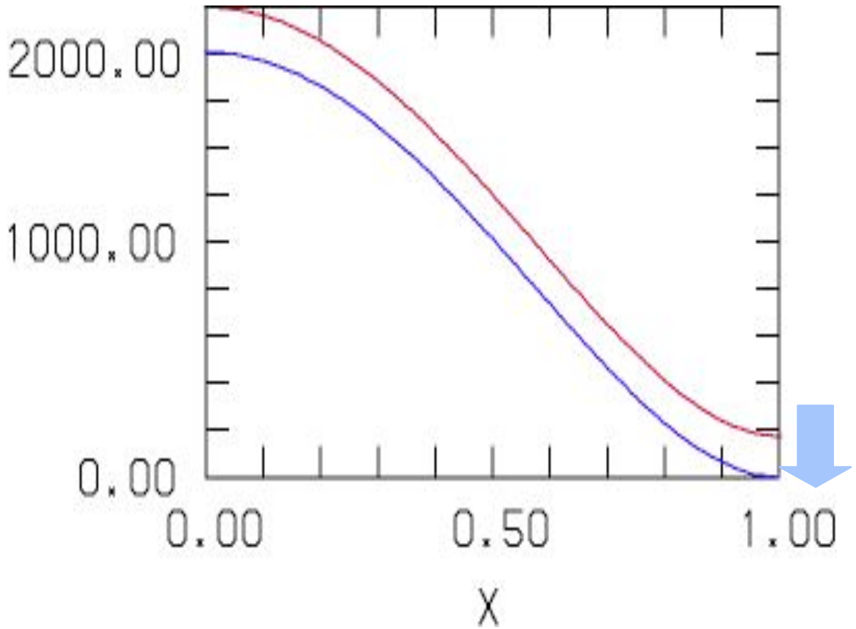


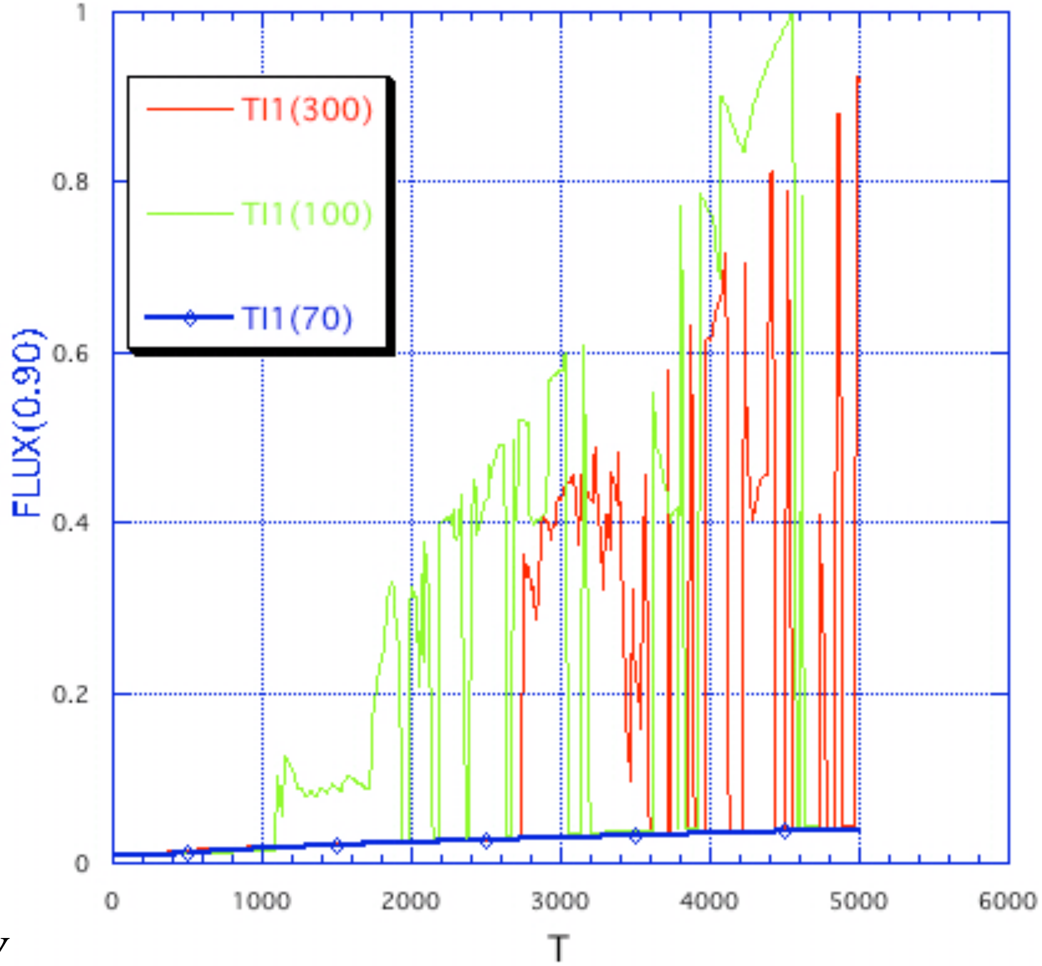
# CASE3: No momentum source $v^{lc} = v^{bv} = 0$

**No Oscillation**



# CASE4: Threshold value of noise for oscillation

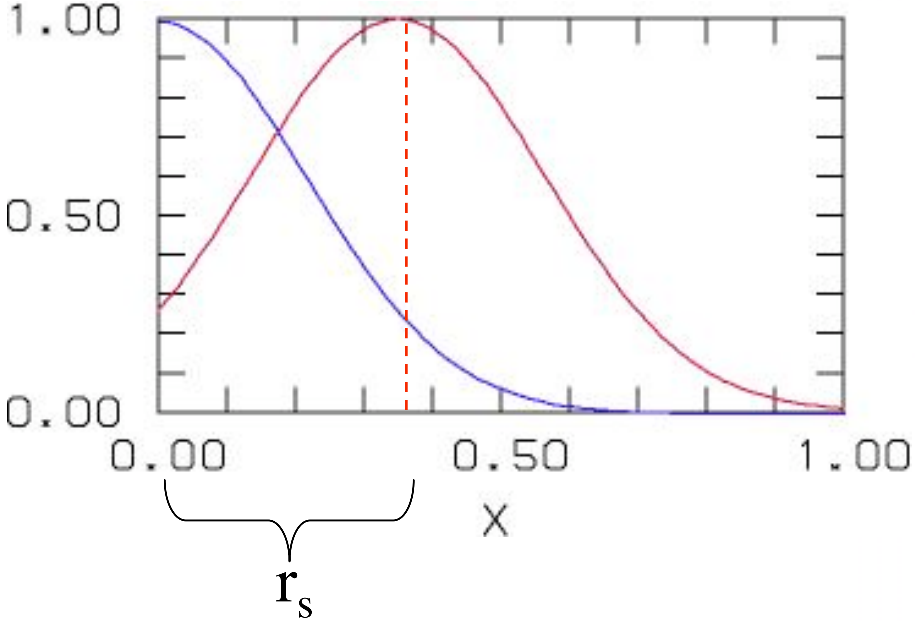


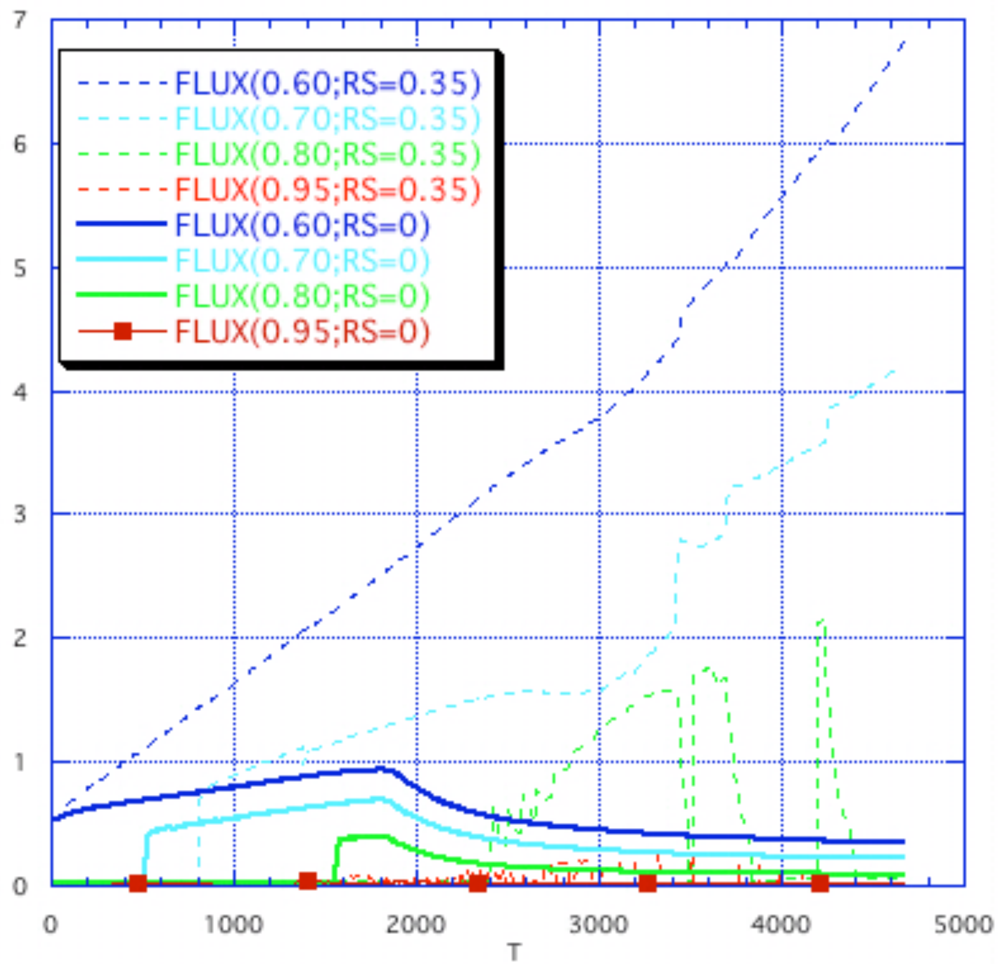




**Oscillation appears for** $T_{i1} \geq 70eV$

# CASE5: Dependence of source profile

$$S = S_0 \exp\{-(r - r_s)^2 / \sigma\}$$




**No oscillation appears for central peaked source profile.**

# Summary I: ITG+$E_r^2$ model

- **Oscillation appears when initial noise is given.**
- **It is due to thermal transport given by marginally unstable ITG**
- **It depends on noise strength, source profile, momentum loss etc.**
- **Check mesh number dependence on oscillation.**

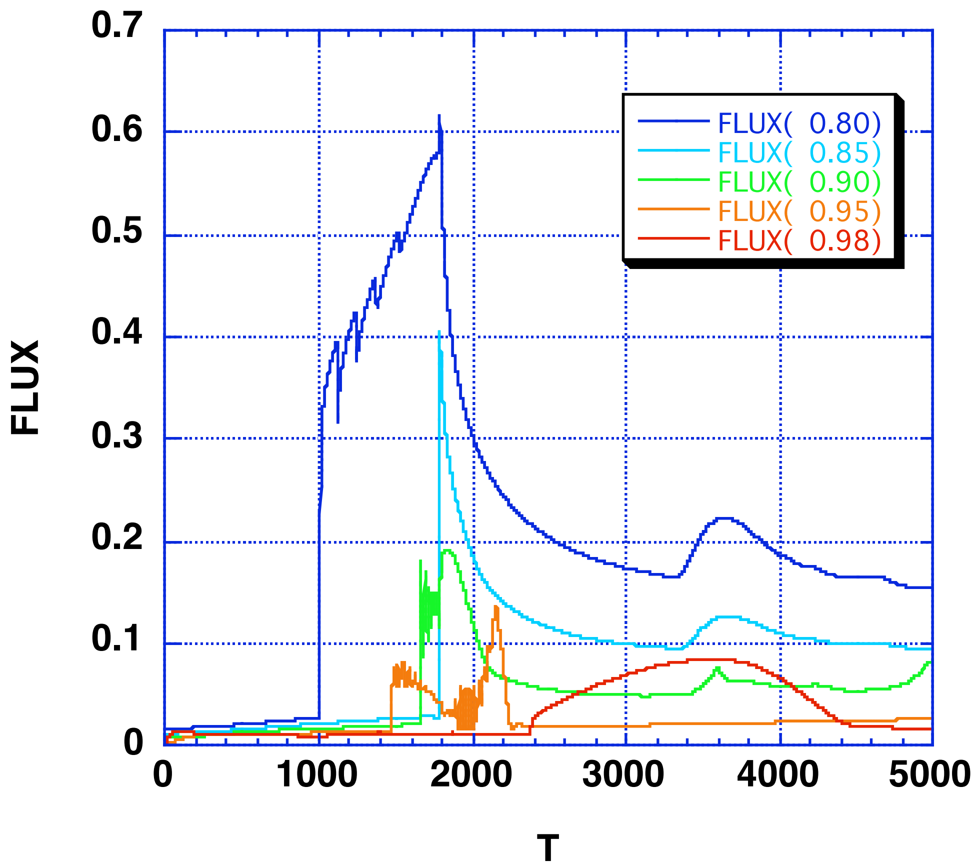
| | | w momentum loss | w/o momentum loss |
|---|---|---|---|
| w/o noise | | X | X |
| w noise ($T_{i1}>70$eV) | $R_s=0$ | X | X |
| | $R_s=3.5$ | O | X |

# ITG+$E_r$ model

T. S. Hahm and K.Burrel, PP 2 1648(1995).

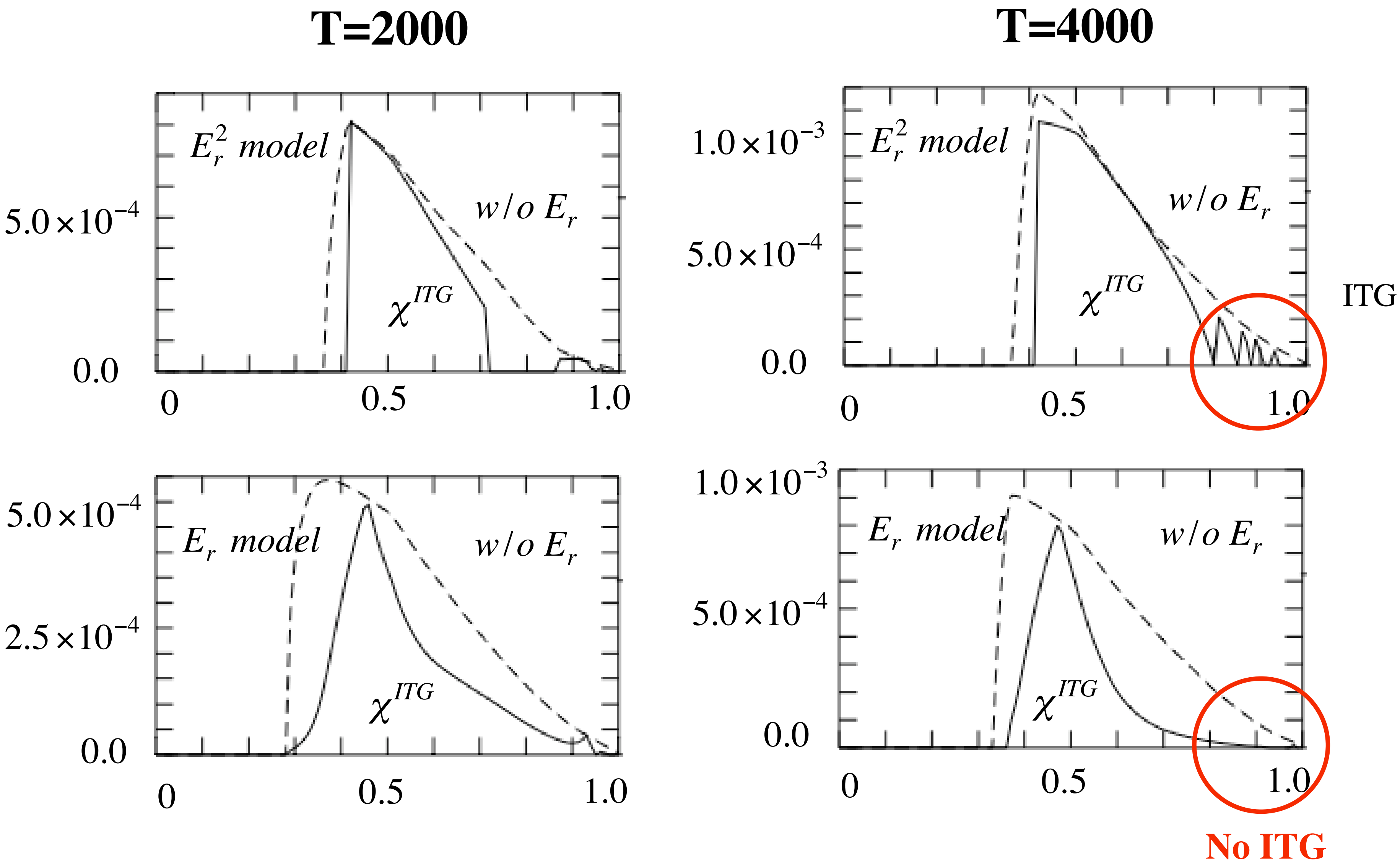
$$\gamma_{E\times B} = \left| \frac{r}{q} \frac{\partial}{\partial r} \frac{q}{r} \frac{cE_r}{B} \right|$$

**Different stability criterion**




Different dynamical behavior of heat flux.

# Profile Evolution



# Summary 2: ITG+$E_r$ model

- $\chi^{ITG}$ obtained from $E_r$ model is ~ factor 2 smaller than that of $E_r^2$ model.
- Since ITG is stable in edge region, no oscillation appears.

# Coupled model with time evolution of diffusivity

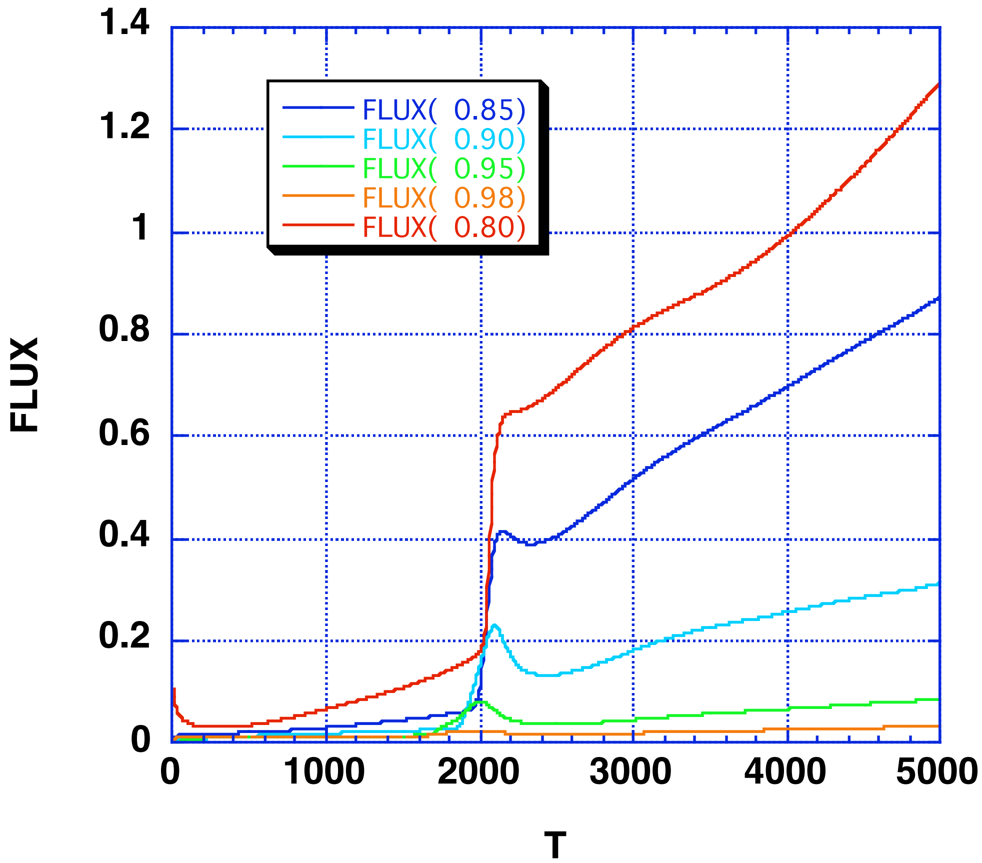
B. A. Carreras, et al., PP 1 4014(1994).

$$\frac{\partial}{\partial \hat{t}} U_p = \frac{a}{\rho_{i0}}\left(\upsilon^{bl} + \upsilon^{lc}\right) + \hat{\mu}\frac{\partial^2}{\partial \hat{r}^2} U_p + \hat{\chi}_c \frac{\partial^2}{\partial \hat{r}^2} U_p$$

$$\frac{3}{2}\frac{\partial}{\partial \hat{t}} T_i = \hat{\mu}\frac{\partial^2}{\partial \hat{r}^2} T_i + \hat{S} + \hat{\chi}_c \frac{\partial^2}{\partial \hat{r}^2} T_i + \hat{\chi}^{NC}\frac{\partial^2}{\partial \hat{r}^2} T$$

$$\frac{\partial}{\partial \hat{t}}\hat{\mu} = (\hat{\chi}^{ITG} - \hat{\mu})\frac{0.04a^2}{\rho_i^2}\hat{\mu} + \hat{\mu}\frac{\partial^2}{\partial \hat{r}^2}\hat{\mu}$$

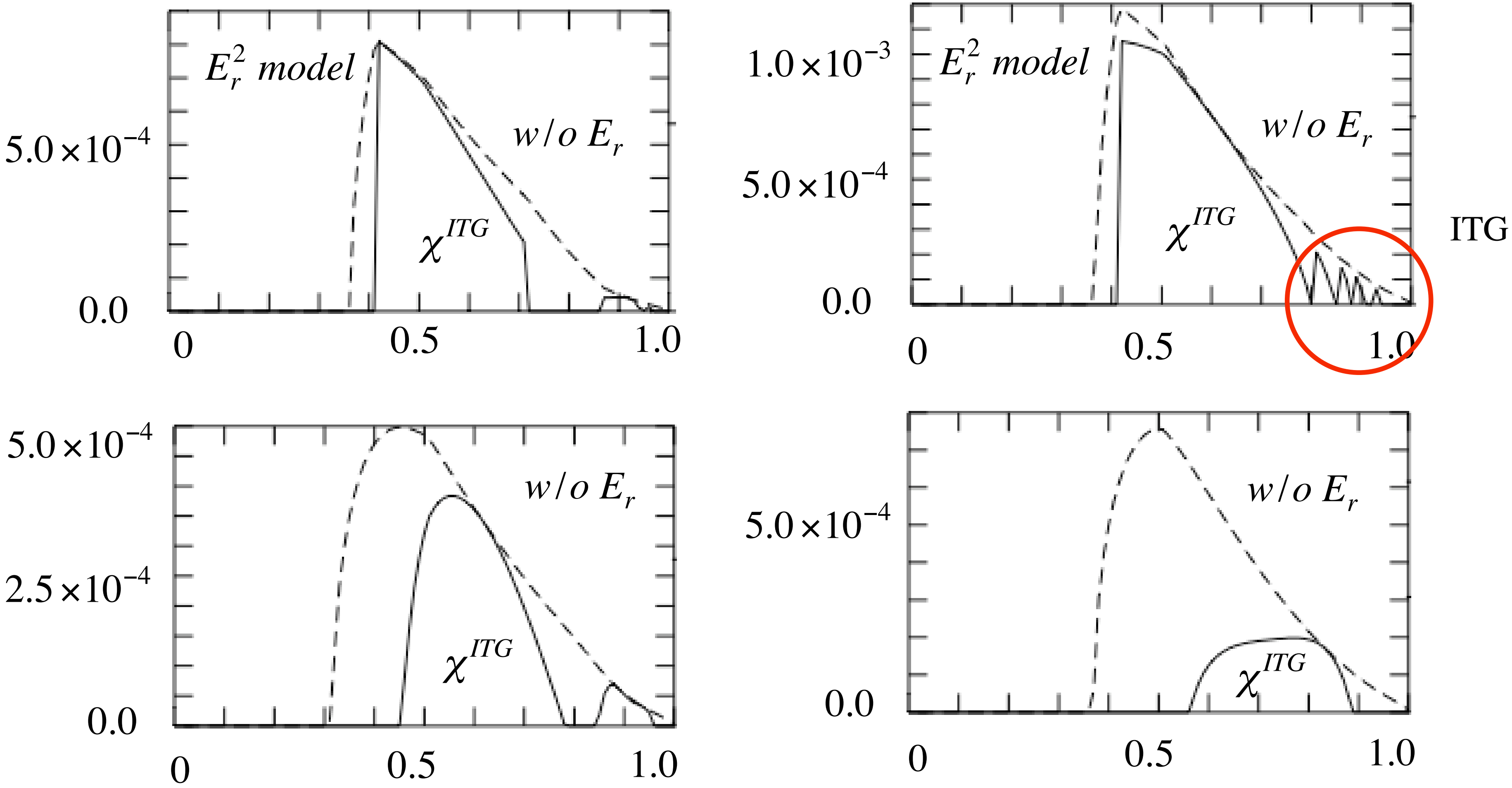
# Same as CASE 2 except time evolution of diffusivity




Different dynamical behavior of heat flux compared with CASE 2.

# Profile Evolution

**T=2000** **T=4000**




$\chi^{ITG}$ evolves different way

# Summary 3: Carreras-Diamond model

- $\chi^{ITG}$ evolves different way compared with conventional model.
- To verify this model, comparison with direct simulation is necessary as a future work.

# Future work

- Investigate toroidal flow effect taking parallel momentum equation into account.
- Develop modules for TASK code.