2nd TM on Theory of Plasma Instabilities:
Transport, Stability and their interaction
Trieste, Italy, 2-4 March 2005

NIFS

Two-dimensional Structure and Particle Pinch in a Tokamak H-mode

N. Kasuya and K. Itoh (NIFS)

Outline

1. Motivation

   H-mode, poloidal shock

2. 2-D Structure

   model

   weak E_r: homogeneous

   strong E_r: inhomogeneous

3. Impact on Transport

   particle pinch,

   ETB pedestal formation

4. Summary

Motivation

H-mode

Improve confinement

Radial structure – studied in detail

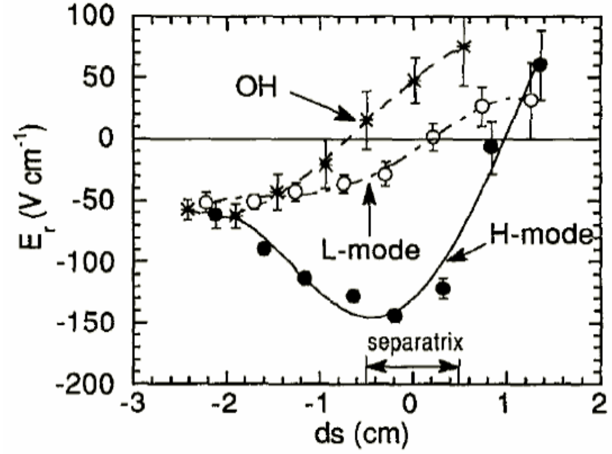
Bifurcation phenomena transition (jump)

Turbulence suppression E × B flow shear

$$D = D_c + \frac{D_{t0}}{1 + (h\ dE_r/dr)^2}$$

K. Itoh, et al., PPCF **38** (1996) 1

e.g.)



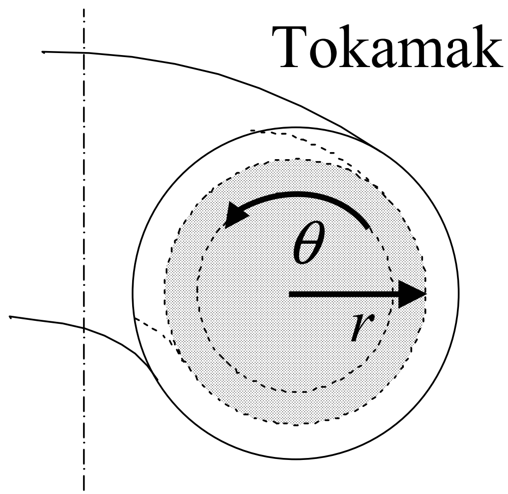
Radial profile of edge electric field in JFT-2M

K. Ida et al., Phys. Fluids B **4** (1992) 2552

Still remain questions.

Q: Fast pedestal formation mechanism?
Particle Pinch effect ?

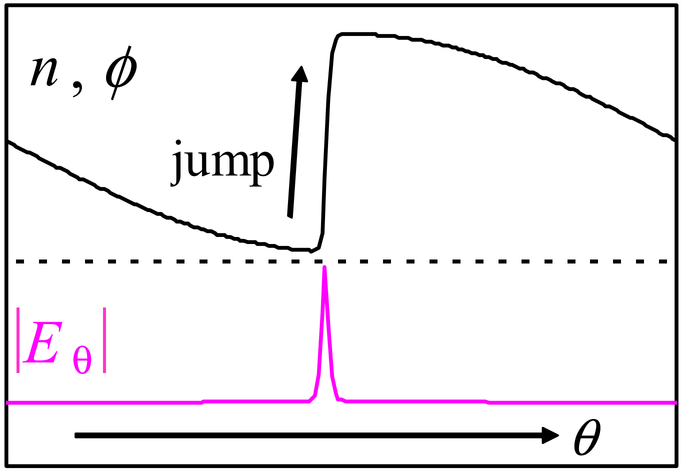
Q: How is two-dimensional (2-D) structure?



Poloidal Shock

Steady jump structure of density and potential when poloidal Mach number $M_p \sim 1$

K. C. Shaing, et al., Phys. Fluids B **4** (1992) 404
T. Taniuti, et al., J. Phys. Soc. Jpn. **61** (1992) 568



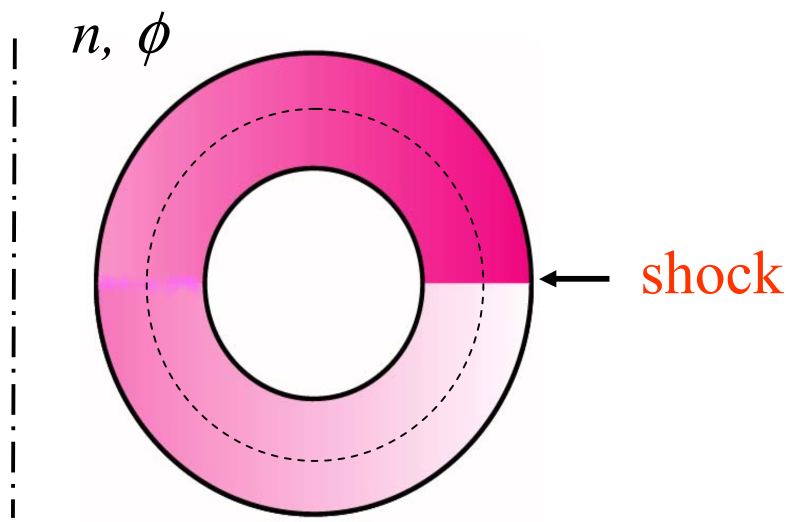
H-mode

Large E × B flow in the poloidal direction

Prediction of appearance of a shock structure

Not much paid attention

Poloidal cross section



Consideration of 2-D structure

Approach

In this research

Density and potential profiles in a tokamak H-mode

Solved as two-dimensional (radial and poloidal) problem

radial structural bifurcation from plasma nonlinear response

+

poloidal shock structure

Both mechanisms are included

Poloidal inhomogeneity $\rightarrow$ radial convective transport

Effect on the density profile formation

2-D Structure

Model

variables $V_p(r)$, $\Phi(r,\theta)$, $n(r,\theta)$

Shear viscosity coupling model

momentum conservation

$$m_i n \frac{d}{dt}\vec{V}_i = \vec{J}\times\vec{B} - \vec{\nabla}(p_i + p_e) - \left(\vec{\nabla}\cdot\overleftrightarrow{\pi}_i\right)_{\text{bulk}} - \left(\vec{\nabla}\cdot\overleftrightarrow{\pi}_i\right)_{\text{shear}}$$

(a) (b) (c)

n : density
$\vec{J}$: current
p : pressure
$\overleftrightarrow{\pi}$: viscosity

$$\Phi(r,\theta) = \Phi_0(r) + \Delta\Phi(r,\theta)$$

poloidal structure $(V\cdot\nabla)V$ …(a)

V_p ↑ parallel component → poloidal component ↑

$\Delta\Phi \leftrightarrow \Delta n$

Boltzmann relation

solved iteratively in shock ordering $\frac{e\Delta\Phi}{T} = O\left(\varepsilon^{1/2}\right)$

Previous L/H transition model bifurcation nonlinearity $\nabla\cdot\pi$ …(b)

$$\left(\vec{B}\cdot\vec{\nabla}\cdot\overleftrightarrow{\pi}_i\right)_{\text{shear}} = -m_i n\mu B\nabla_\perp^{\,2}V_{//}$$

radial and poloidal coupling …(c)

V_{p}, Φ_0 Poloidal component (flux surface average) (i)

$$\left\langle -\frac{nI}{KB^2 rR}\frac{\partial \Phi}{\partial \theta}\frac{\partial}{\partial r}\left[\frac{1}{2}\left(\frac{KB_{\mathrm{p}}}{n}\right)^2\right] + \frac{B_{\mathrm{p}}}{r}\frac{\partial}{\partial \theta}\left[\frac{1}{2}\left(\frac{KB_{\mathrm{p}}}{n}\right)^2\right]\right\rangle$$

$$= \frac{1}{m_{\mathrm{i}}}\left\langle \frac{JB_{\mathrm{p}}B_{\varsigma}}{n}\right\rangle - \frac{1}{m_{\mathrm{i}}}\left\langle \frac{\vec{B}_{\mathrm{p}}\cdot\vec{\nabla}\cdot\vec{\pi}_{\mathrm{i}}}{n}\right\rangle_{\mathrm{bulk}} - \frac{1}{m_{\mathrm{i}}}\left\langle \frac{\vec{B}_{\mathrm{p}}\cdot\vec{\nabla}\cdot\vec{\pi}_{\mathrm{i}}}{n}\right\rangle_{\mathrm{shear}}$$

$\Delta\Phi$ Parallel component (ii)

Substitution of obtained $V_{\mathrm{p}}(\mathrm{r})$

$$-\frac{nI}{KB^2 rR}\frac{\partial \Phi}{\partial \theta}\frac{\partial}{\partial r}\left[\frac{1}{2}\left(\frac{KB}{n}\right)^2\right] + \frac{B_{\mathrm{p}}}{r}\frac{\partial}{\partial \theta}\left[\frac{1}{2}\left(\frac{KB}{n}\right)^2\right] + \frac{IB_{\varsigma}}{B^2 rR}\frac{\partial \Phi}{\partial \theta}\frac{\partial}{\partial r}\left[\frac{I}{RB_{\mathrm{p}}B_{\varsigma}}\frac{\partial \Phi}{\partial r}\right] - \frac{KB_{\mathrm{p}}B_{\varsigma}}{nr}\frac{\partial}{\partial \theta}\left[\frac{I}{RB_{\mathrm{p}}B_{\varsigma}}\frac{\partial \Phi}{\partial r}\right]$$

$$= -\frac{B_{\mathrm{p}}}{m_{\mathrm{i}} r}\frac{\partial}{\partial \theta}\left(\frac{\langle P_{\mathrm{e}}\rangle}{\langle n\rangle}\ln n + \frac{5}{2}\frac{\langle P_{\mathrm{i}}\rangle}{\langle n^{5/3}\rangle} n^{2/3}\right) - \frac{1}{m_{\mathrm{i}} n}\left(\vec{B}\cdot\vec{\nabla}\cdot\vec{\pi}_{\mathrm{i}}\right)_{\mathrm{bulk}} - \frac{1}{m_{\mathrm{i}} n}\left(\vec{B}\cdot\vec{\nabla}\cdot\vec{\pi}_{\mathrm{i}}\right)_{\mathrm{shear}}$$

Response between n and Φ Boltzmann relation $n = \bar{n}\exp\dfrac{e\Delta\Phi}{T}$

Variables $K(r)$, $\Phi(r,\theta)$, $n(r,\theta)$ $\quad K = \dfrac{nV_{\mathrm{p}}}{B_{\mathrm{p}}}$

N. Kasuya et al., J. Plasma Fusion Res. in press

(i) Radial Solitary Structure

Electrode Biasing

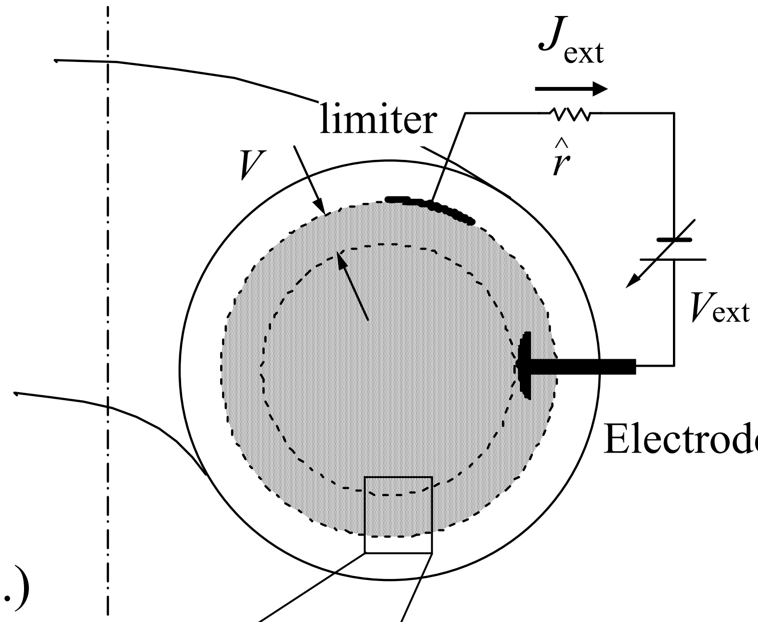
Charge conservation law

$$\frac{\partial}{\partial t} E_r = -\frac{1}{\varepsilon_0 \varepsilon_\perp} (J_{visc} + J_r - J_{ext})$$

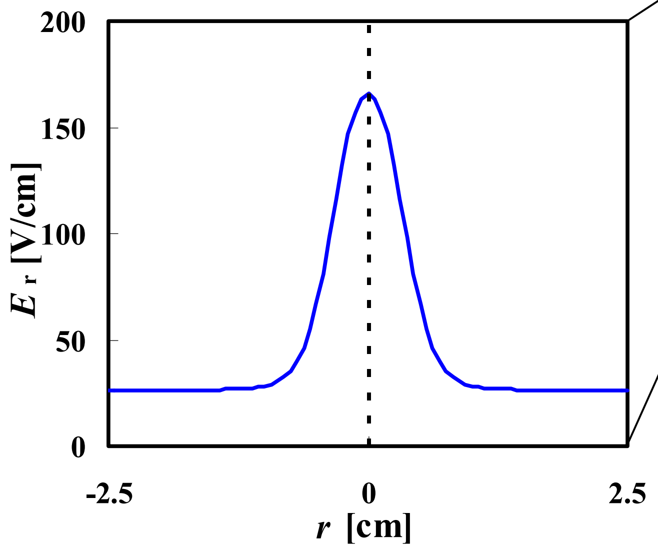
J_{visc} : shear viscosity of ions (anomalous)

J_r : bulk viscosity (neoclassical)

J_{ext} : external current (electrode, orbit loss, etc.)



R. R. Weynants et al., Nucl. Fusion **32** (1992) 837.



radial structure

stable solitary solutions

N. Kasuya, et al., Nucl. Fusion **43** (2003) 244

Flux surface averaged quantities

(ii) Poloidal Variation

$V_{\rm r}/V_{\rm p} << 1 \;\; (K(\psi))$, $\left(\vec{B}\cdot\vec{\nabla}\cdot\vec{\pi}_{\rm i}\right)_{\rm shear} = -m_{\rm i} n \mu B \nabla_{\perp}{}^{2} V_{//}$

$$-\hat{\mu} r^2 \frac{B_0}{B_{\rm p}} \frac{\partial^2}{\partial r^2}\left\{M_{\rm p}\left[\exp(-\chi)-1\right]\right\} + \frac{2}{3} D \exp(-\chi)\frac{\partial^2 \chi}{\partial \theta^2} + \left(1-M_{\rm p}{}^2\right)\frac{\partial \chi}{\partial \theta} + 2A\frac{\partial \chi^2}{\partial \theta}$$
$$= \varepsilon\left(\left\{D - \hat{\mu}\frac{B_0}{B_{\rm p}}\left[2r^2\frac{\partial^2 M_{\rm p}}{\partial r^2} + 4r\frac{\partial}{\partial r}M_{\rm p} - 2M_{\rm p}\right]\right\}\cos\theta - 2M_{\rm p}{}^2 \sin\theta\right)$$

$\hat{\mu} = 0 \rightarrow$ Previous works (Shaing, Taniuchi)

$\chi = \ln\left(n/\bar{n}\right)$: density (to be obtained)

$M_{\rm p} = \dfrac{KB_0}{\bar{n} v_{\rm ti} C_{\rm r}}$: poloidal Mach number (from Eq. in (i))

Solve this equation to obtain 2-D χ profile

$\hat{\mu} = \dfrac{\mu}{r v_{\rm ti} C_{\rm r}}$ $\quad K = \dfrac{n V_{\rm p}}{B_{\rm p}}$ $\quad A = \dfrac{M_{\rm p}{}^2}{2} + \dfrac{5}{36}\dfrac{1}{C_{\rm r}{}^2}$ $\quad C_{\rm r}{}^2 = \left[\dfrac{5}{3} + \dfrac{T_{\rm e}}{T_{\rm i}}\right]\Big/ 2$ $\quad D = \dfrac{4\sqrt{\pi}}{3}\dfrac{I_{\rm ps} K B_0}{\bar{n} v_{\rm ti} C_{\rm r}{}^2}$

Simplified case $\quad M_{\rm p}$: giving a solitary profile

strong toroidal damping

boundary condition : $\chi = 0$

L-mode

Weak flow, homogeneous E_r case

$M_p = 0.33$ (spatially constant)

Boundary condition

$\Delta\Phi = 0$ at $r - a = 0, -5$[cm]

$R = 1.75$[m], $a = 0.46$[m],

$B_0 = 2.35$[T], $T_i = 40$[eV],

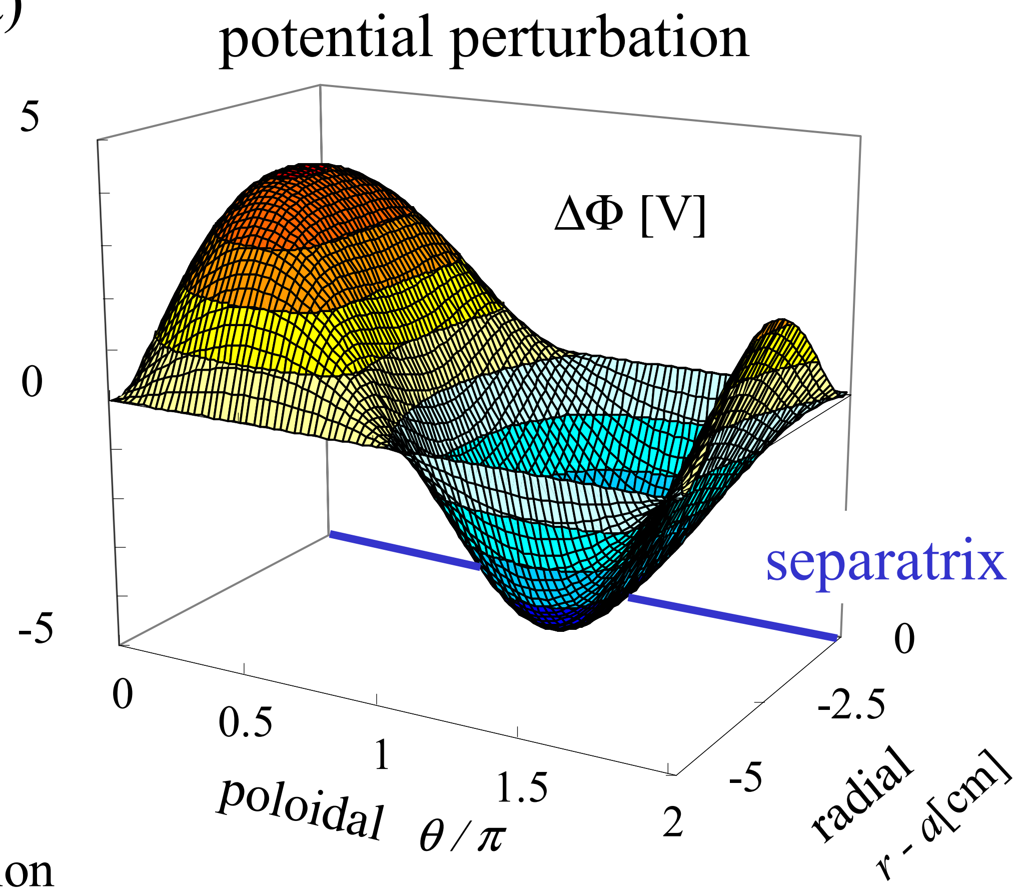
$I_p = 200$[kA]

$\mu = 1.0[m^2/s]$

gradual spatial variation

no shock

μ: relative strength of radial diffusion to poloidal structure formation



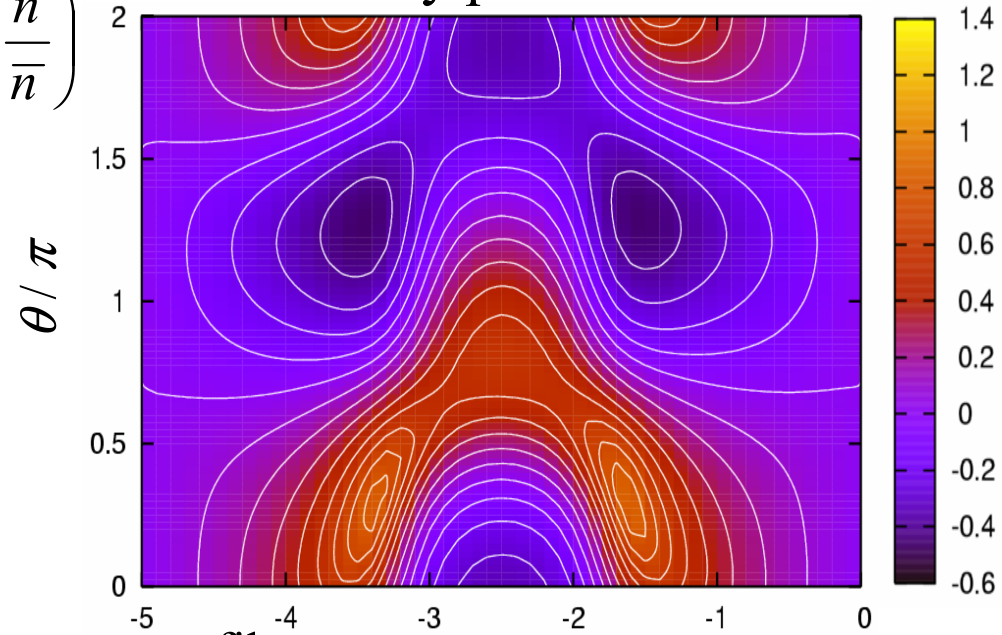
N. Kasuya et al., submitted to J. Plasma Fusion Res.

Strong E_r

$\mu = 1 [m^2/s]$ (experimentally, intermediate case)

Density perturbation

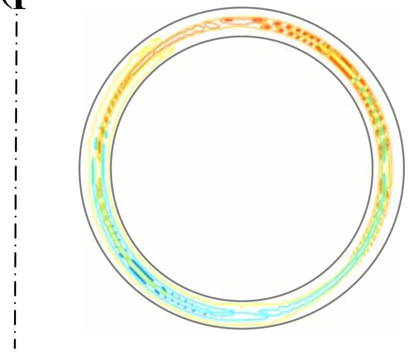
$\ln\left(\frac{n}{\bar{n}}\right)$



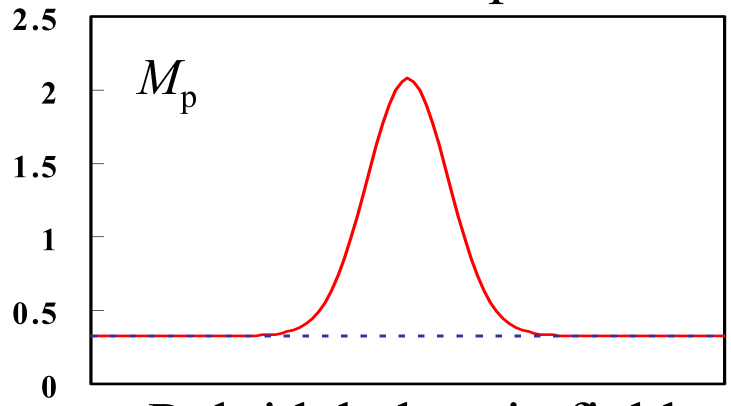
r - *a* [cm]

n profile

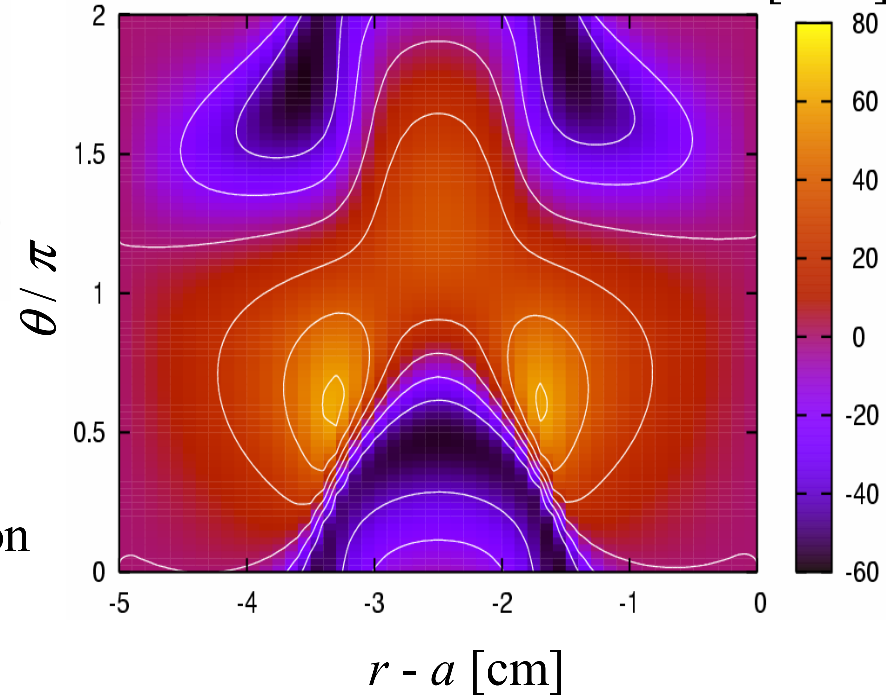
(poloidal cross section)



Poloidal flow profile



Poloidal electric field [V/m]



r - *a* [cm]

Boltzmann relation

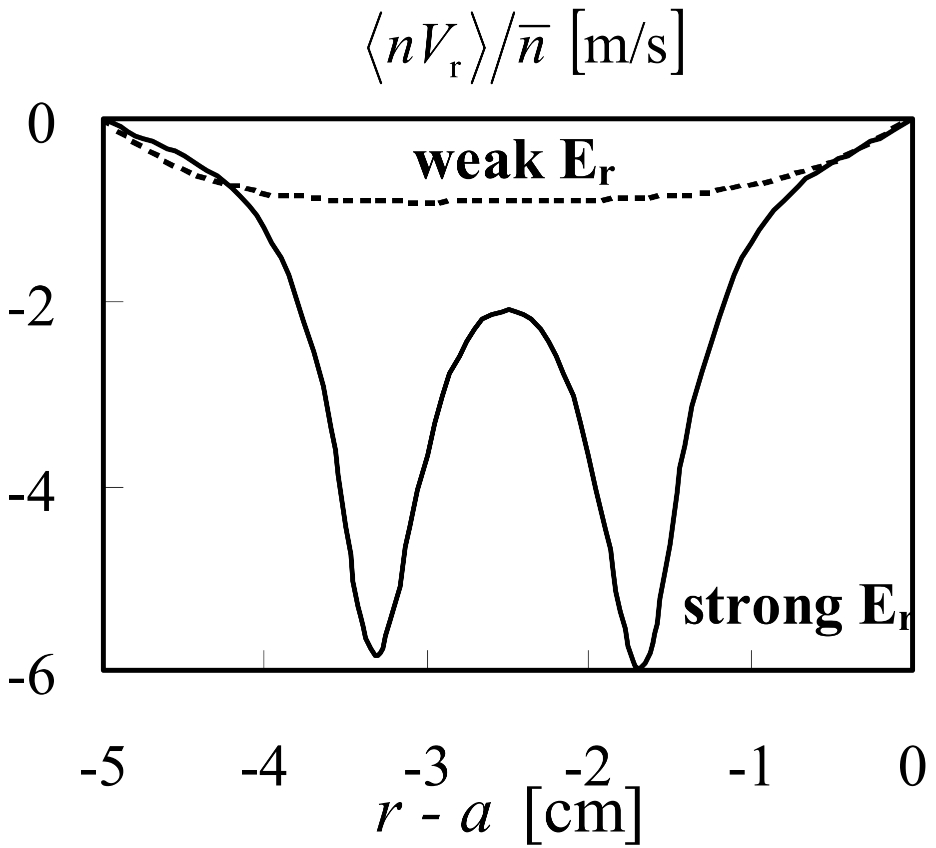
$$n = \bar{n} \exp \frac{e\Delta\Phi}{T}$$

Effect on Transport

Radial Flux

$$\langle nV_r \rangle = \left\langle n\frac{E_\theta}{B} \right\rangle = \frac{1}{2\pi B_0}\int nE_\theta (1+\varepsilon\cos\theta)^2 d\theta$$

Inward flux arises from poloidal asymmetry.



Inward flux is larger in the shear region.

shear viscosity term

$$\left(\vec{B}\cdot\vec{\nabla}\cdot\vec{\pi}_i\right)_{shear} = -m_i n \mu \underline{B} \underline{\nabla_\perp^2 V_{//}}$$

poloidal asymmetry

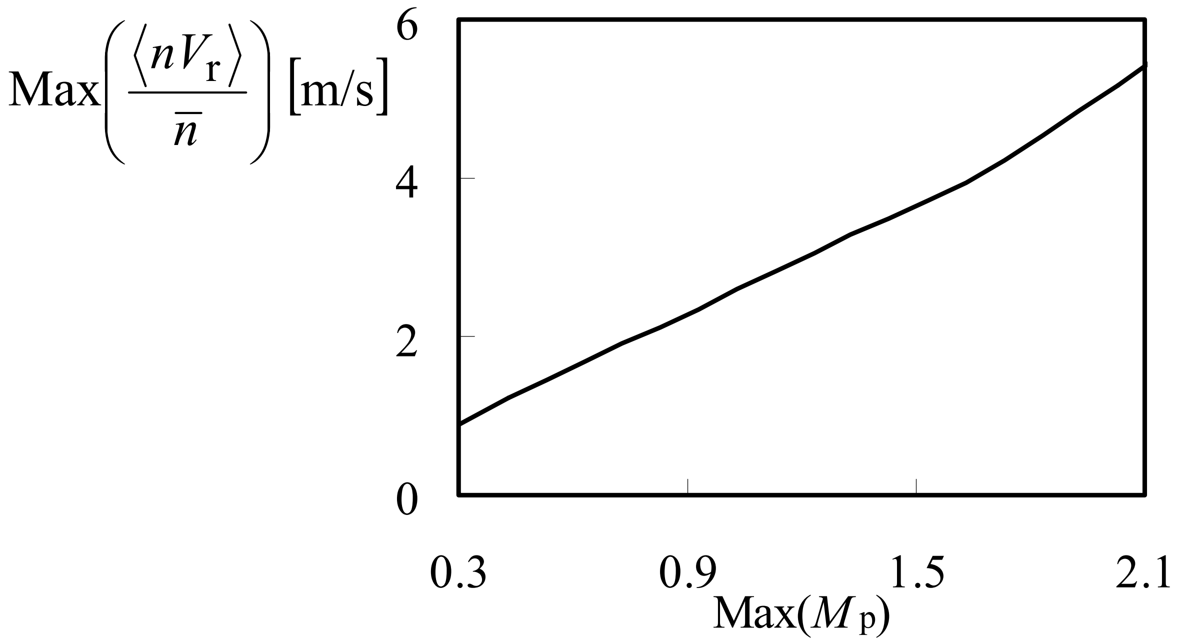
gradient and curvature

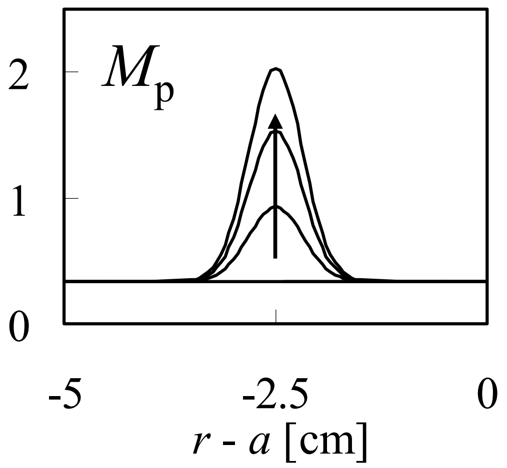
Impact on Transport (1)

Inward Pinch

If poloidal asymmetry exists, it brings particle flux that can determine the density profile.

Asymmetry coming from toroidicity gives $V_r \sim O(1)$[m/s]





increase of convective transport

Impact on Transport (2)

L/H Transition

Inside the shear region

local poloidal flow
$\rightarrow$ 2-D shock structure
$\rightarrow$ averaged inward flux

Transition

suppression of turbulence
and reduction of diffusive transport
(Well known)
+
sudden increase of convective transport
(New finding)

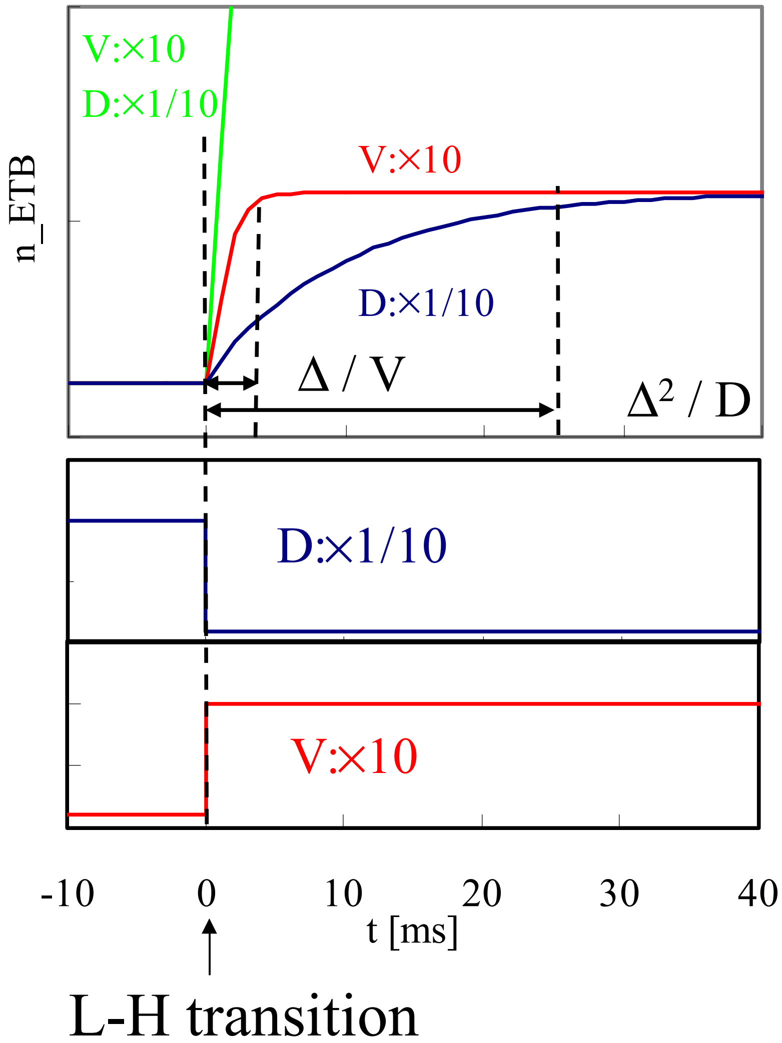
continuity equation

$$\frac{\partial n}{\partial t} = -\nabla\left(\underbrace{nV}_{\text{convective}} - \underbrace{D\nabla n}_{\text{diffusive}}\right)$$

$V_r \nearrow$ $D \searrow$

Rapid Formation of ETB Pedestal

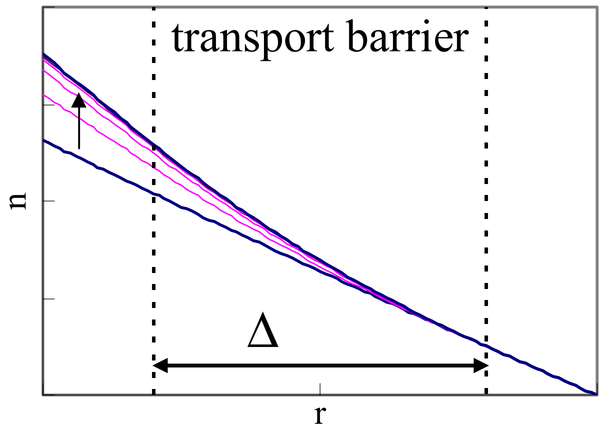
Density profile



Influence of the jump in convection

Transport suppression only gives slow ETB pedestal formation.

Sudden increase of the convective flux induces the rapid pedestal formation.



Direction of Convective Velocity

Direction of particle flux can be changed by inversion of

$$M_p\ (E_r),\ \ B_t,\ \ I_p$$

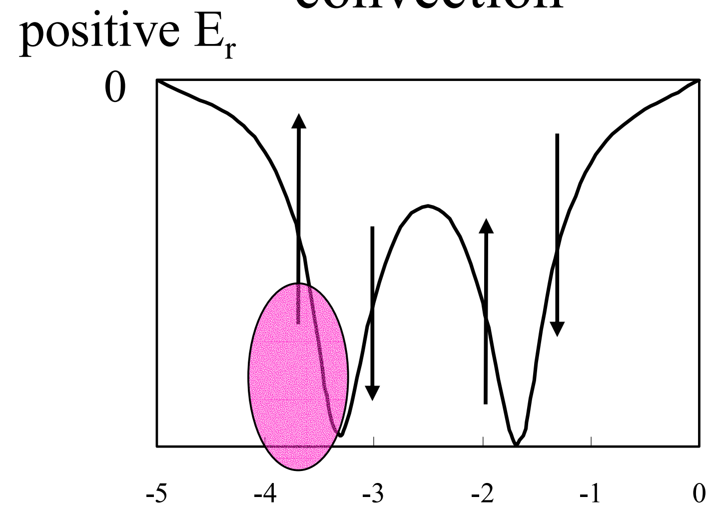
Divergence of particle flux leads the density to change.

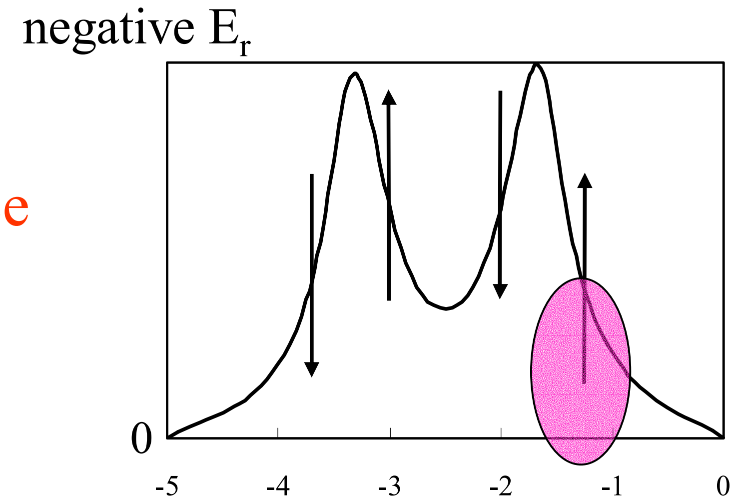
$$\frac{\partial n}{\partial t} = -\nabla\left(\underline{nV} - D\nabla n\right) + S$$

Sign of the electric field makes a difference in the position of the pedestal.

The particle source and the boundary condition are important to determine the steady state.

convection





increase of density

Summary

Multidimensionality is introduced into H-mode barrier physics in tokamaks.

radial steep structure in H-mode + poloidal shock structure

Shear viscosity coupling model shock ordering

structural bifurcation from nonlinearity

Poloidal flow makes poloidal asymmetry and generates non-uniform particle flux.

inward pinch $V_r \sim$ O(1-10)[m/s]

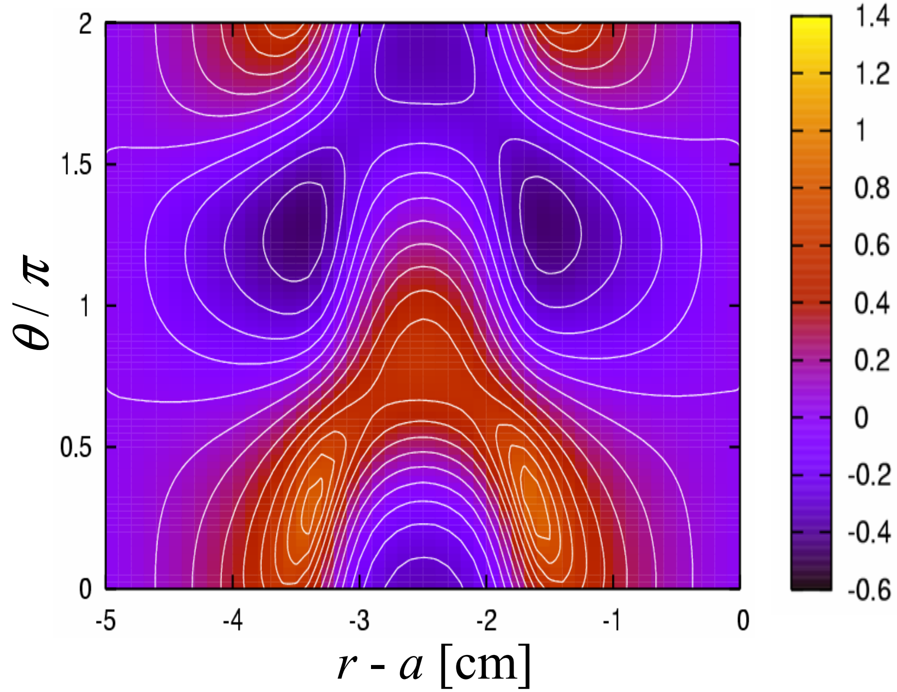
Sudden increase of convective transport in the shear region.

This gives new explanation of fast H-mode pedestal formation.

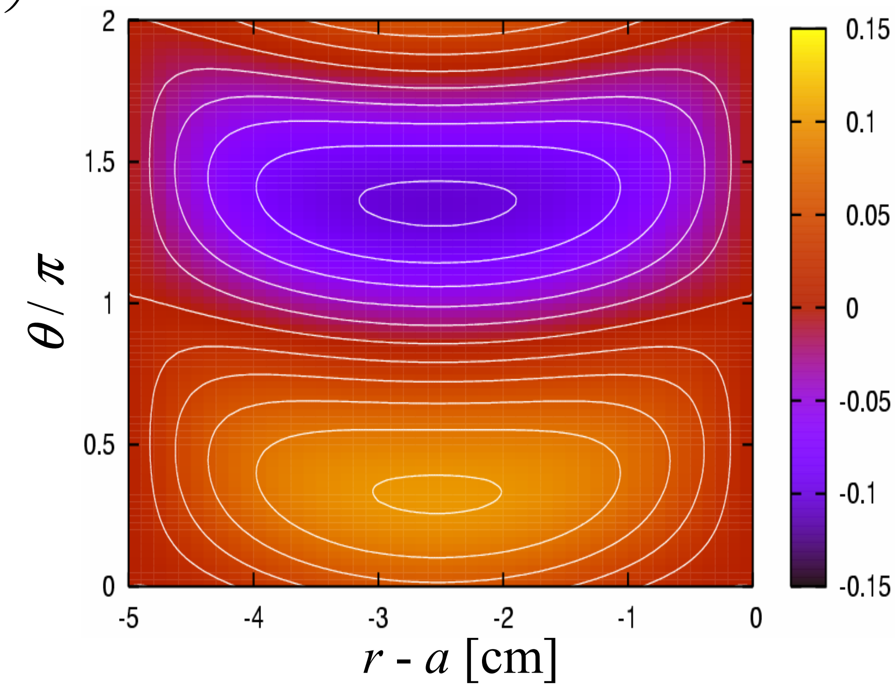
The steepest density position in ETB changes in accordance with the direction of E_r, B_t and I_p.

Strong and Weak E_r

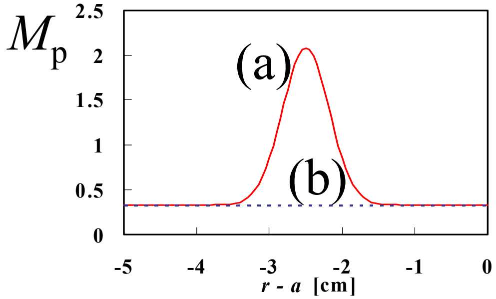
(a) Strong inhomogeneous E_r



(b) Weak homogeneous E_r



poloidal flow profile



Strong	Weak
$\Delta\Phi_{\max} \sim 50[\mathrm{V}]$	$\Delta\Phi_{\max} \sim 4[\mathrm{V}]$
$E_{\theta\max} \sim 63[\mathrm{V/m}]$	$E_{\theta\max} \sim 9[\mathrm{V/m}]$
$V_{r\max} \sim 28[\mathrm{m/s}]$	$V_{r\max} \sim 4[\mathrm{m/s}]$

$\mu = 1[\mathrm{m^2/s}]$

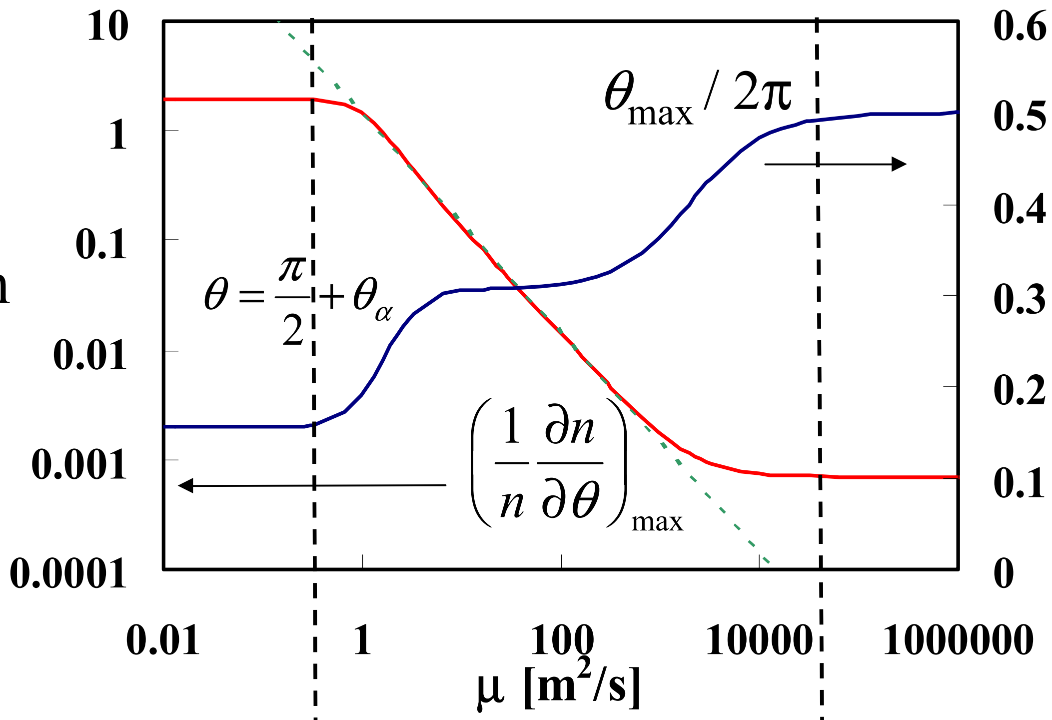
Radial and Poloidal Coupling

Fast rotating case

M_p=1.2 :const

Shear viscosity μ controls the strength of coupling.

Steepness and position of the shock



$$\left(\frac{1}{n}\frac{\partial n}{\partial \theta}\right)_{\max} = \frac{3\varepsilon}{2D}\sqrt{2M_p^{\ 2} + D^2}\left[\cos(\theta_{\mathrm{shock}} + \theta_\alpha) + 1\right]$$

Shock region

Intermediate region

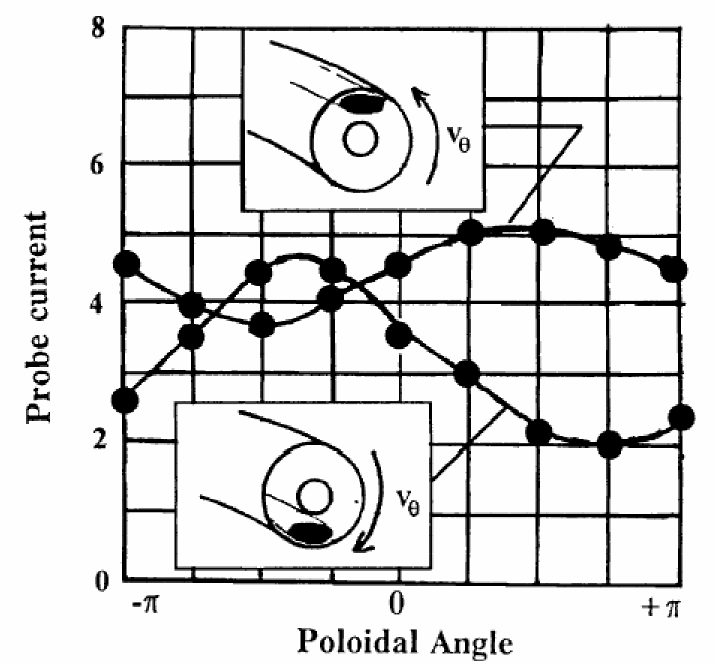
$$\left(\frac{1}{n}\frac{\partial n}{\partial \theta}\right)_{\max} \propto \frac{1}{\mu}$$

Viscosity region

$$\left(\frac{1}{n}\frac{\partial n}{\partial \theta}\right)_{\max} \sim \frac{\varepsilon d^2}{4a^2}$$

Remark on Experiment

Poloidal density profile in electrode biasing H-mode in CCT tokamak

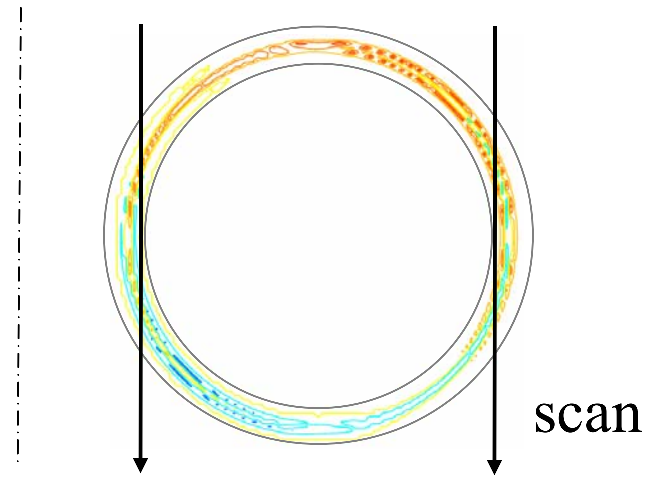


G. R. Tynan, et al., PPCF **38** (1996) 1301

2D structure!

To observe the poloidal structure, identification of measuring points on the same magnetic surface is necessary.

Alternative way: measurement of up-down asymmetry in various locations



The shock position differs in accordance with M_p, so controlling the flow velocity by electrode biasing will be illuminating.

Inversion of E_r, B_t and I_p

Model equation

$$-\mu' r^2 \frac{B_0}{B_p}\frac{\partial^2}{\partial r^2}\{M_p[\exp(-\chi)-1]\} + \frac{2}{3}D\exp(-\chi)\frac{\partial^2\chi}{\partial\theta^2} + (1-M_p{}^2)\frac{\partial\chi}{\partial\theta} + 2A'\frac{\partial\chi^2}{\partial\theta}$$

$$= \varepsilon\left(\left\{D - \mu'\frac{B_0}{B_p}\left[2r^2\frac{\partial^2 M_p}{\partial r^2} + 4r\frac{\partial}{\partial r}M_p - 2M_p\right]\right\}\cos\theta - 2M_p{}^2\sin\theta\right)$$

— : shear viscosity   direction of the flux (not change) by inversion of B_t or I_p

— : poloidal shock   direction of the flux (change) by inversion of B_t or I_p

L-mode – shear viscosity dominant, H-mode – shock dominant

In spontaneous H-mode

B_t and I_p are co-direction → outward flux

counter-direction → inward flux

M_p: × -1 → $\Phi_-(\theta) = \Phi_+(-\theta)$

Basic Equations

Momentum conservation   ion + electron

$$m_i n \frac{d}{dt}\vec{V}_i = \vec{J}\times\vec{B} - \vec{\nabla}(p_i + p_e) - \vec{\nabla}\cdot\vec{\pi}_i \qquad (1)$$

$\vec{J}$: current p : pressure $\vec{\pi}$: viscosity n : density

$$\vec{V} = \vec{V}_{//} + \frac{\vec{E}\times\vec{B}}{B^2} = \begin{pmatrix} -\dfrac{I}{rRB^2}\dfrac{\partial\Phi}{\partial\theta} \\ \dfrac{KB_p}{n} \\ \dfrac{KB_\zeta}{n} - R\dfrac{\partial\Phi}{\partial\psi} \end{pmatrix}$$

← **radial flow**

$K \equiv \dfrac{nV_p}{B_p}$ $I = R^2\vec{B}\cdot\nabla\varsigma$ Φ : potential

toroidal symmetry

Radial and poloidal components are coupled
with radial flow and shear viscosity

strong poloidal shock case — Eq. (2) poloidal structure
Eq. (3) radial structure

$$\left(\vec{B}\cdot\vec{\nabla}\cdot\vec{\vec{\pi}}_{\mathrm{i}}\right)_{\mathrm{shear}} = -m_{\mathrm{i}} n \mu \vec{B}\cdot\nabla_{\perp}{}^{2}\vec{V}$$

μ : shear viscosity

$$\left(\vec{B}\cdot\vec{\nabla}\cdot\vec{\vec{\pi}}_{\mathrm{i}}\right)_{\mathrm{bulk}} = \frac{2}{3}\frac{B_{\mathrm{p}}}{r}\frac{\partial}{\partial\theta}\left(p_{//}-p_{\perp}\right)-\left(p_{//}-p_{\perp}\right)\frac{B_{\mathrm{p}}}{B}\frac{1}{r}\frac{\partial B}{\partial\theta}$$

Nonlinearity with the electric field of bulk viscosity
→ structural bifurcation

solitary structure — N. Kasuya, et al., Nucl. Fusion **43** (2003) 244

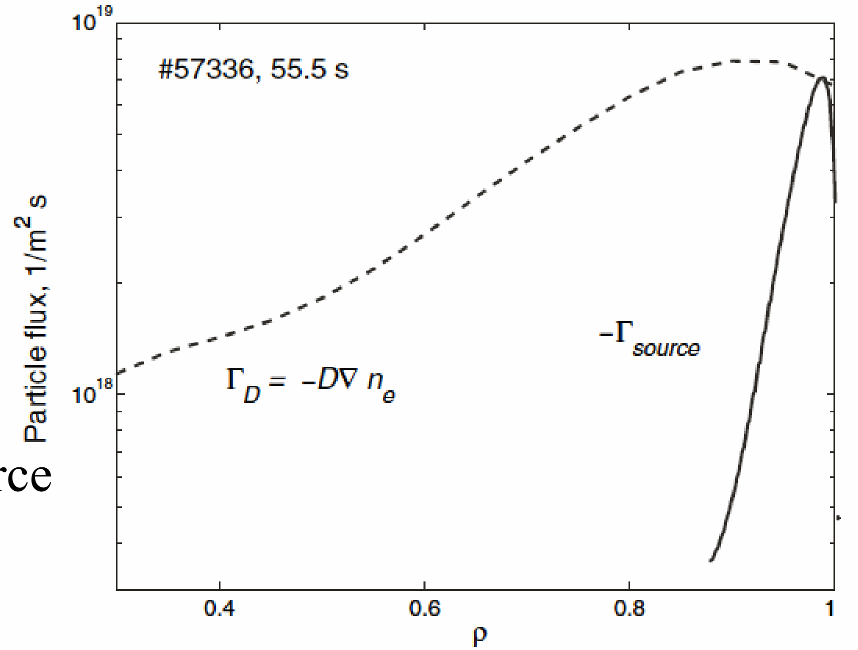
Transport

continuity equation

$$\frac{\partial n}{\partial t} = -\nabla\left(\underline{nV} - \underline{D\nabla n}\right) + S$$

convective diffusive

n: density, V: flow velocity,
D : diffusion coefficient, S: particle source



Radial profiles of particle source and diffusive particle flux in JET
H. Weisen, et al., PPCF **46** (2004) 751

peaked profile ← inward pinch

$$V_r \sim 1[\mathrm{m/s}]$$

Origin of inward pinch has not been clarified yet.

Ware pinch (toroidal electric field)
← inward pinch exists in helical systems U. Stroth, et al., PRL **82** (1999) 928
anomalous inward pinch (turbulence) X. Garbet, et al., PRL **91** (2003) 035001

H-mode

Formation of edge transport barrier (ETB)

Self-sustaining loop of plasma confinement

causality

Pressure gradient, Plasma parameters ←

↓

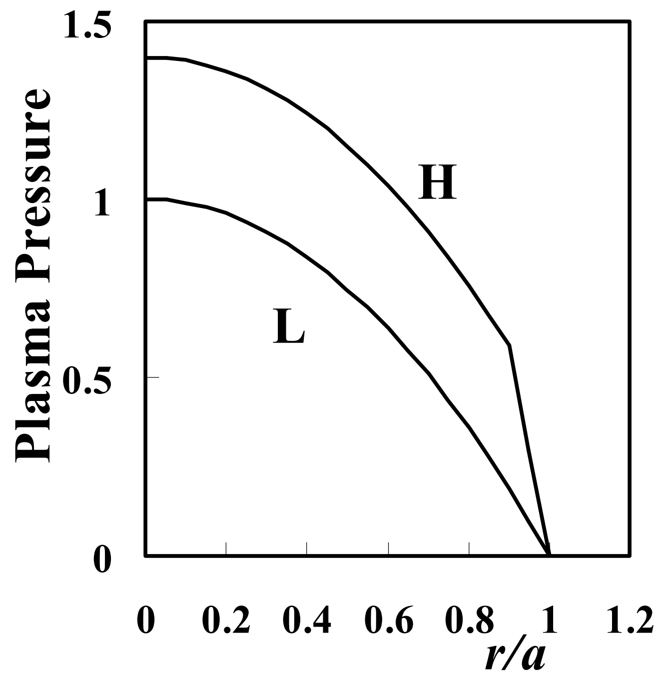
Radial electric field structure ← Electrode biasing

↓

Increase of E × B flow shear

↓

Suppression of anomalous transport



steep radial electric field structure

K. Ida, PPCF **40** (1998) 1429

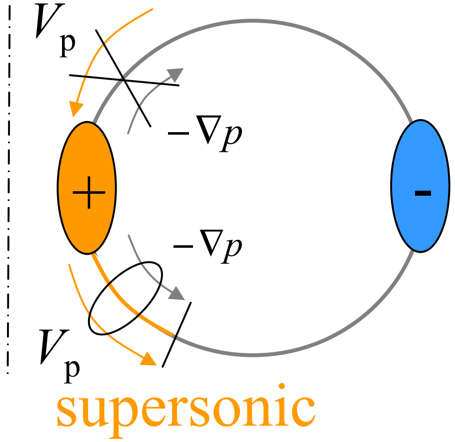
Understanding the structural formation mechanism is important.

Large E × B flow in the poloidal direction

poloidal Mach number $M_{\mathrm{p}} \sim O(1)$

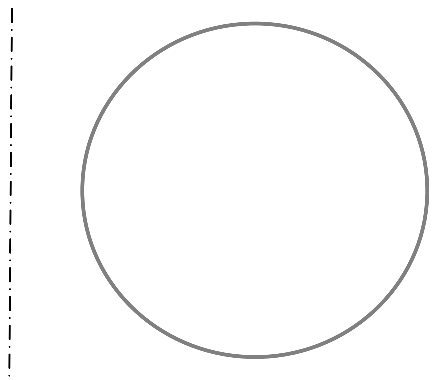
Shock Formation

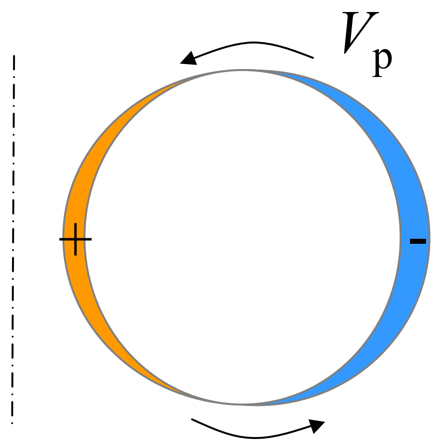
when $M_p \sim 1$



A shock structure appears at the boundary between the supersonic and subsonic region

Effect of the higher order term appears, and the poloidal shock is formed.





Subsonic ∇p dominant
homogeneous

Supersonic $(V \cdot \nabla)V$ dominant
large density in high field side
from compressibility, nV_p=const

H-mode Pedestal

Steep density profile is formed near the plasma edge just after L/H transition.

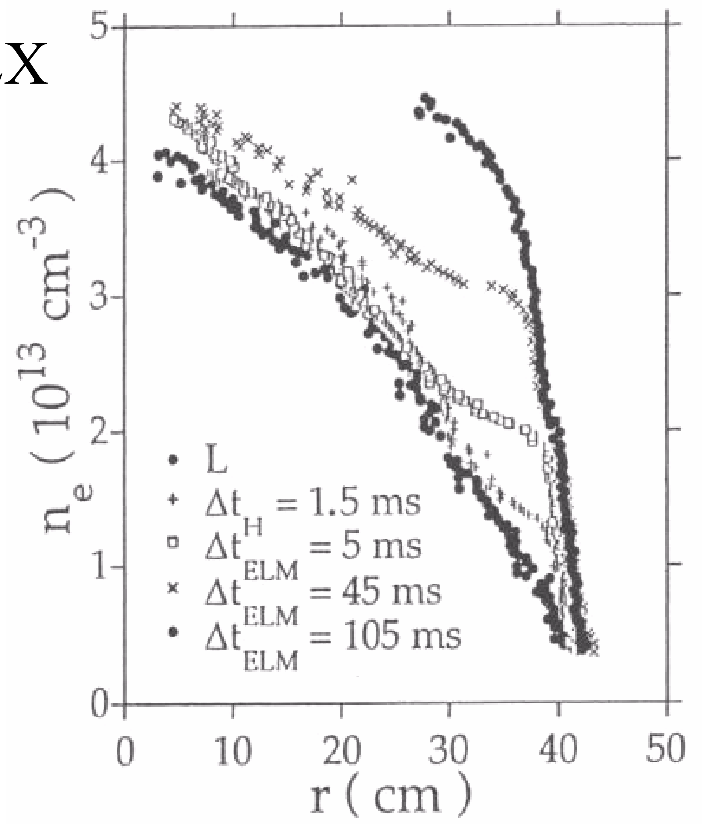
rapid formation

$\Delta t \ll 10$[ms]

Reduction of diffusive transport only cannot explain this short duration.

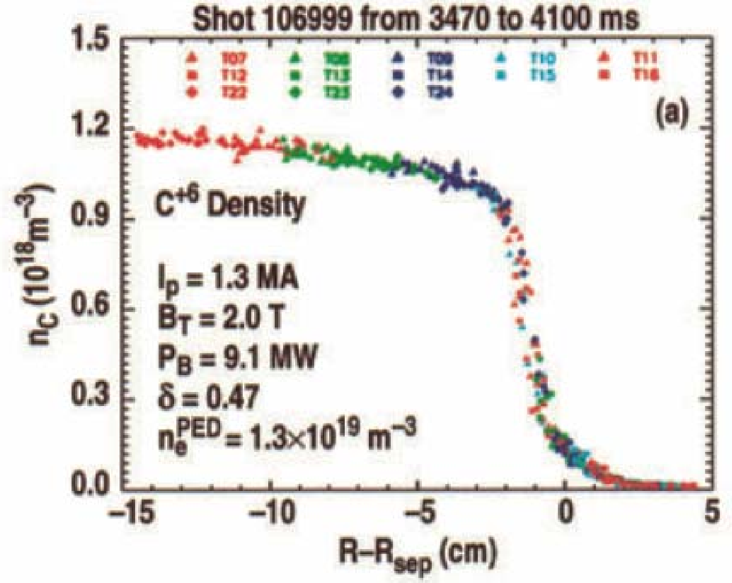
Pedestal formation in H-mode

ASDEX

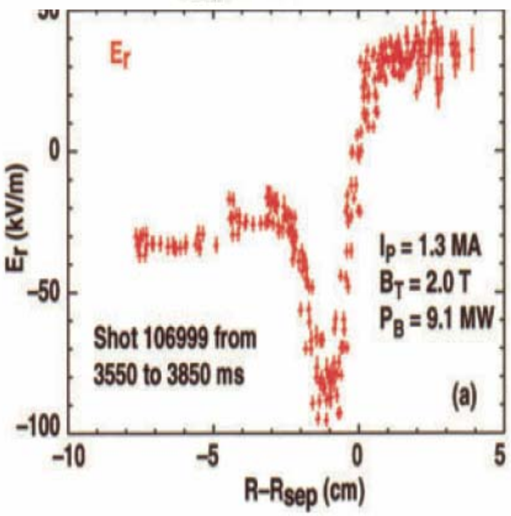


F. Wagner, et al., Proc. 11th Int. Conf.,Washington,1990, IAEA 277

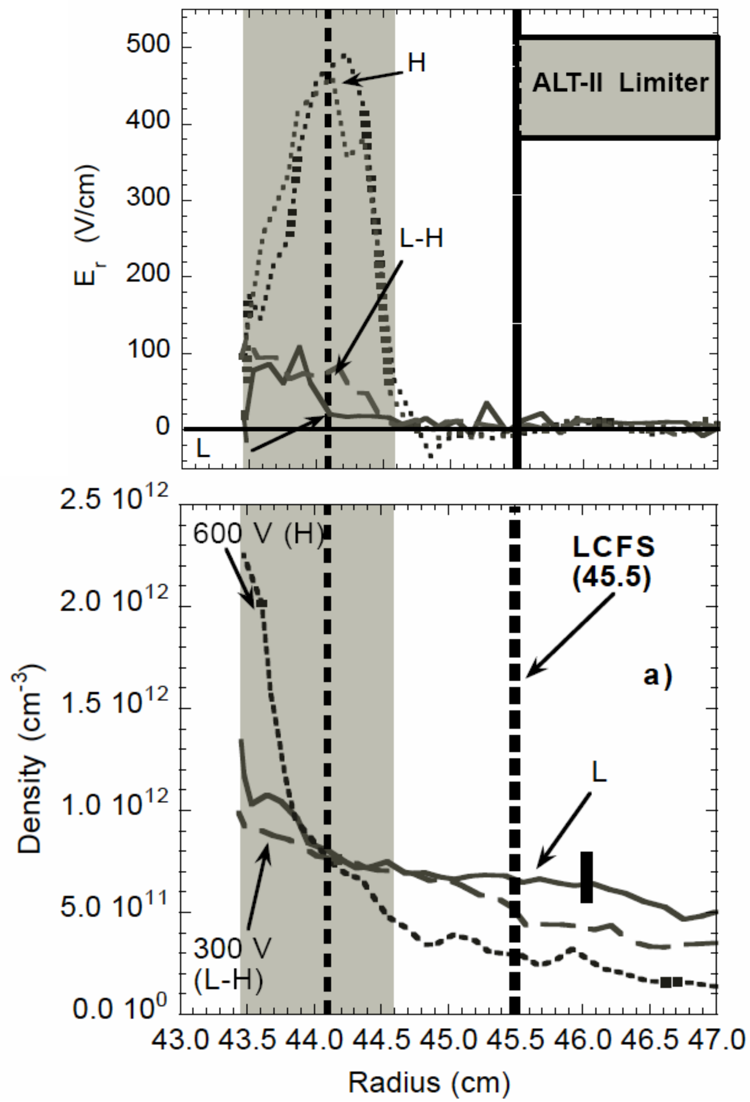
Profile



Shot 106999 from 3470 to 4100 ms
T07 T12 T22
T08 T13 T23
T09 T14 T24
T10 T15
T11 T16
(a)
C+6 Density
Ip = 1.3 MA
BT = 2.0 T
PB = 9.1 MW
δ = 0.47
ne PED = 1.3×10^19 m^-3
nC (10^18 m^-3)
R–Rsep (cm)



Er
Ip = 1.3 MA
BT = 2.0 T
PB = 9.1 MW
Shot 106999 from
3550 to 3850 ms
(a)
Er (kV/m)
R–Rsep (cm)



H
ALT-II Limiter
L-H
L
Er (V/cm)
600 V (H)
LCFS
(45.5)
a)
L
300 V
(L-H)
Density (cm^-3)
Radius (cm)

Poloidal Shock

$\mu = 0$ (no radial coupling, Shaing model) μ : shear viscosity

$$\frac{2}{3} D \frac{\partial \chi}{\partial \theta} + \left(1 - M_p{}^2\right)\chi + 2A'\left(\chi^2 - \left\langle \chi^2 \right\rangle\right) = \varepsilon\left[2M_p{}^2 \cos\theta + D \sin\theta\right]$$

LHS 1st term : viscosity (pressure anisotropy)

2nd term : difference between convective derivative $(V \cdot \nabla)V$ and pressure ∇p

3rd term : nonlinear term

RHS $\chi = \dfrac{e\Delta\Phi}{T_e}$: toroidicity

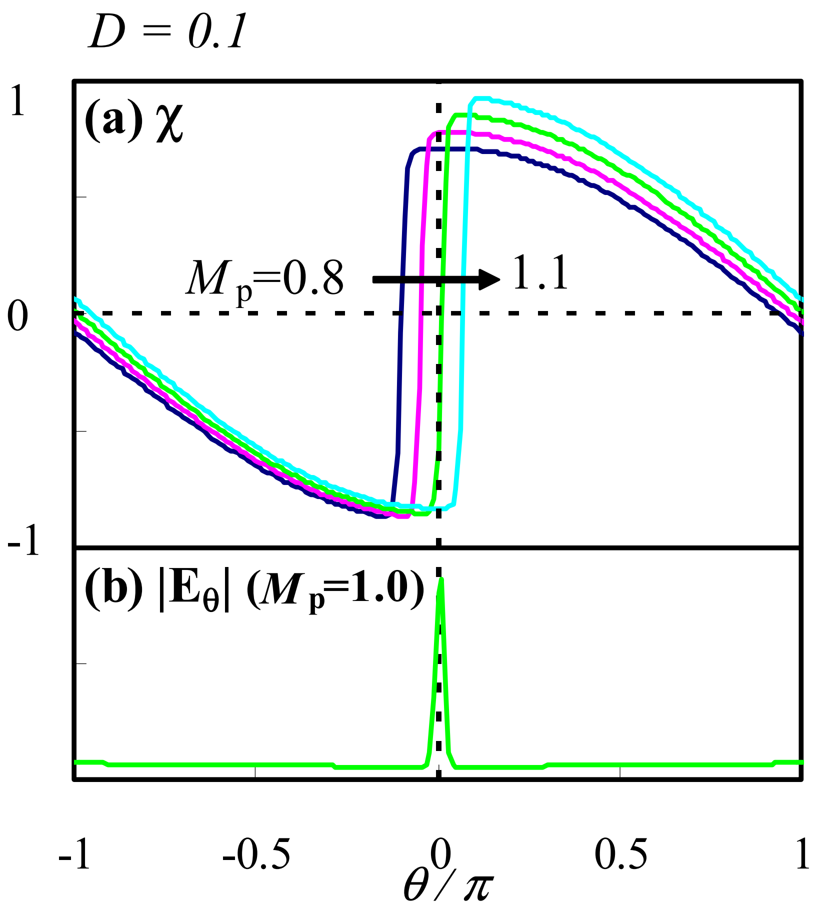
potential perturbation (Boltzmann relation)

$M_p << 1$ ∇p dominant homogeneous structure

$M_p >> 1$ $(V \cdot \nabla)V$ dominant larger density in the high field side

$M_p \sim 1$ competitive, shock formation affected by nonlinearity of the higher order

Shock solutions



sharpness of shock

$$\left.\frac{\partial \chi'}{\partial \theta'}\right|_{\max} = \frac{3\varepsilon}{2D}\sqrt{\left(M_p^{\ 2}+2C\right)+D^2}\left[\cos\left(\theta_{shock}+\theta_\alpha\right)+1\right]$$

$$\propto \frac{1}{D} \qquad (D << 1) \tag{4}$$

position of shock

$$\theta_{shock} = -\theta_\alpha + 2\arcsin\frac{\pi\left|1-M_p^{\ 2}\right|}{8\sqrt{A'\varepsilon\sqrt{\left(M_p^{\ 2}+2C\right)+D^2}}} \tag{5}$$

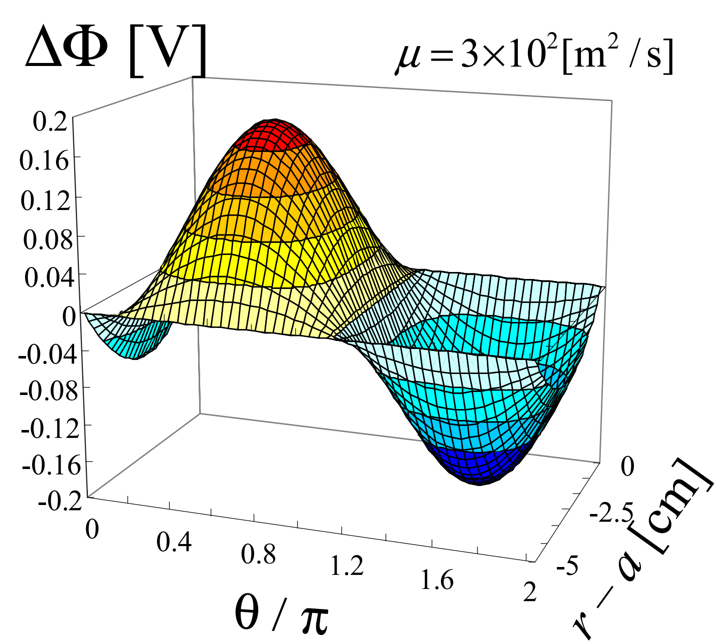
$$\tan\theta_\alpha = -\frac{D}{M_p^{\ 2}+2C}$$

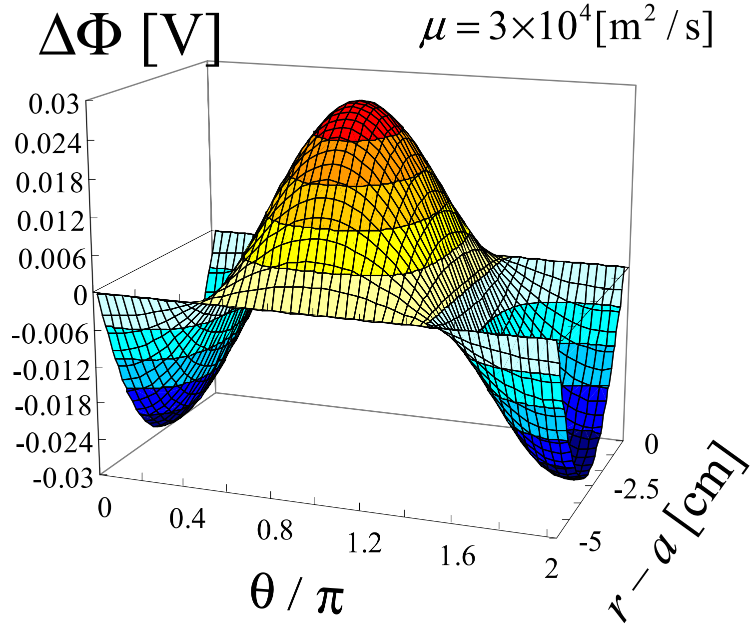
dependence on M_p

Potential Profile

$$1 >> \mu' \frac{B_0}{B_p} >> \frac{Dd^2}{12a^2 M_p}$$

$$\mu' \frac{B_0}{B_p} >> 1$$



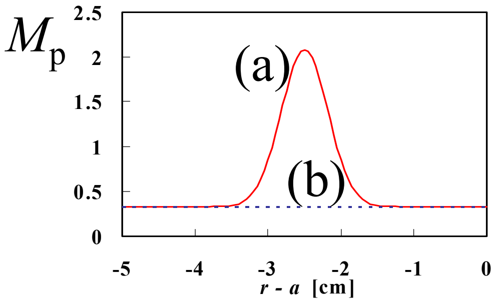


$$\chi(r,\theta) \sim \frac{\varepsilon\sqrt{D^2 + 4M_p{}^4}}{2\mu' a^2 M_p}\frac{B_p}{B_0} \times (r-a)(r-a+d)\sin(\theta+\theta_\alpha) \propto \frac{1}{\mu}$$

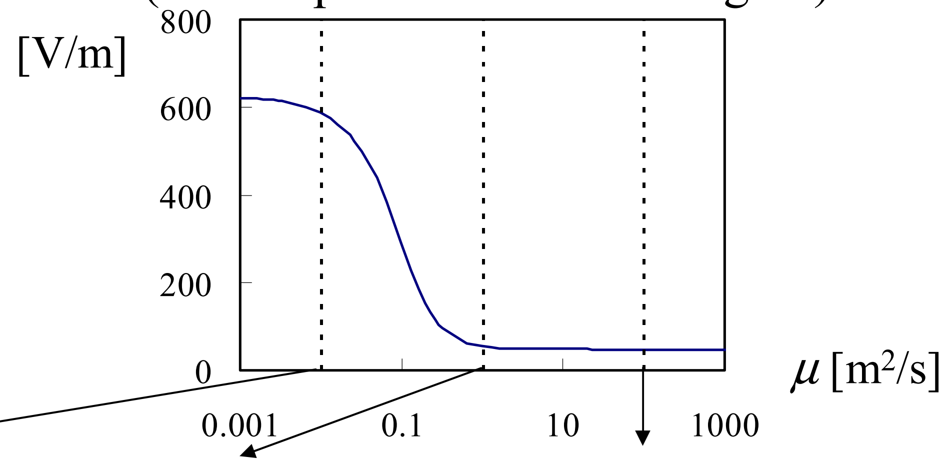
$$\chi(r,\theta) \sim \frac{\varepsilon}{a^2}(r-a)(r-a+d)\cos\theta$$

2-D Structure

Poloidal flow profile



Maximum of the poloidal electric field
(middle point of the shear region)



Shock region

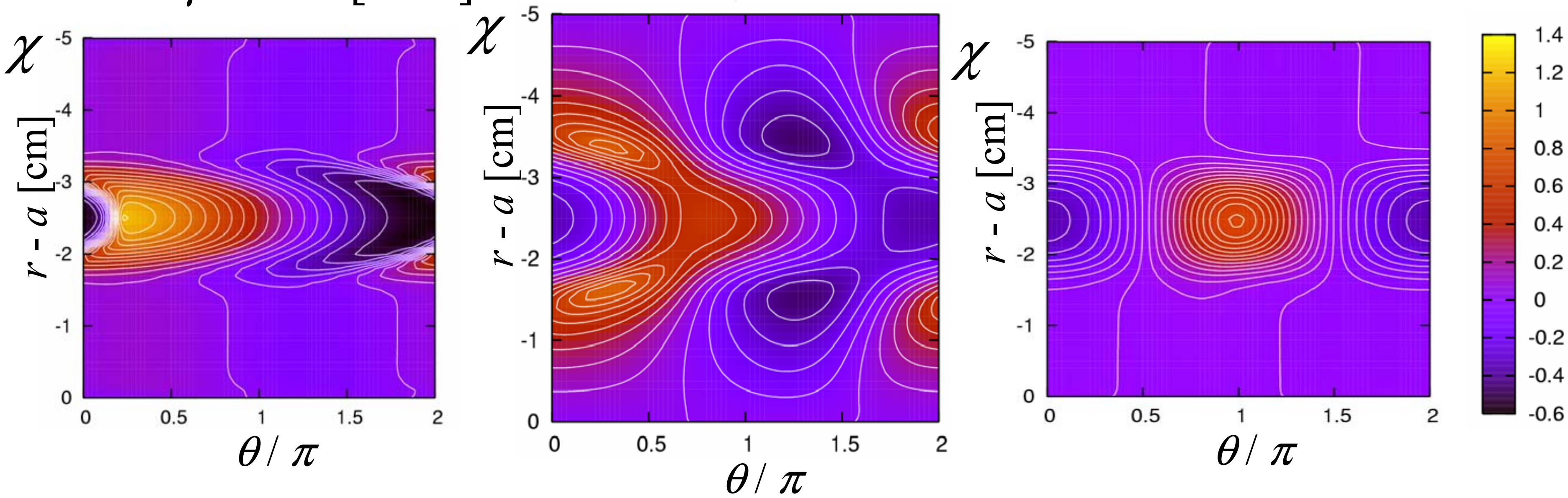
μ =0.01[m²/s]

Intermediate region

μ =1[m²/s]

Viscosity region

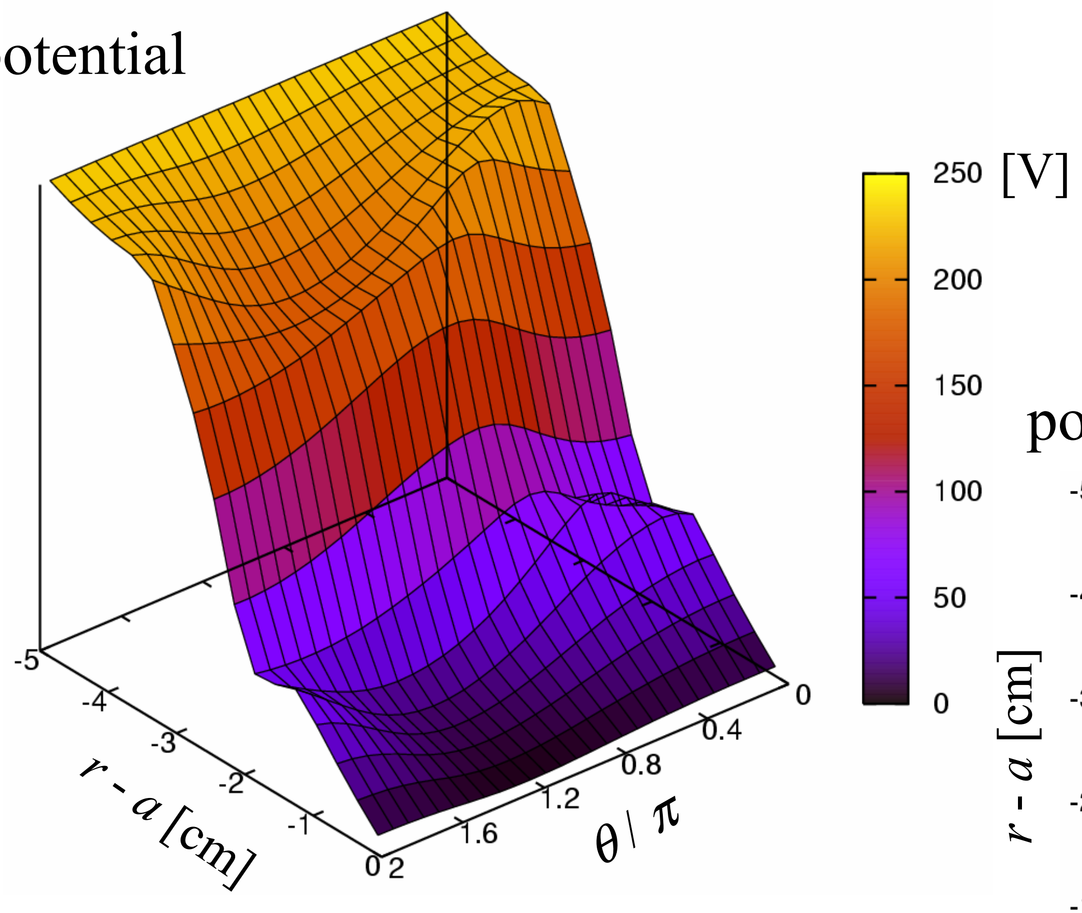
μ =100[m²/s]



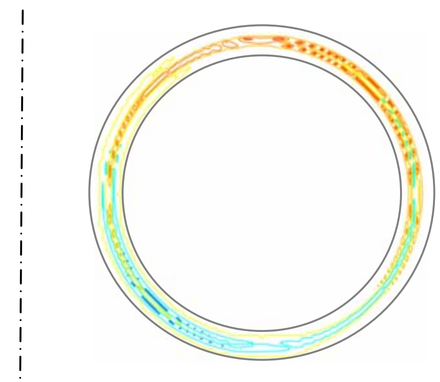
Intermediate case

$\mu = 1[m^2/s]$

potential



χ profile (poloidal cross section)



poloidal electric field