# Isotope effects in internal transport barrier strength on Large Helical Device

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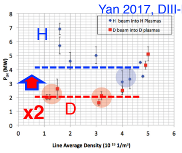
## Introduction

In the case of tokamaks,

$$\tau_E = C I^{\alpha_I} B^{\alpha_B} \overline{n}^{\alpha_n} P^{\alpha_P} R^{\alpha_R} \kappa^{\alpha_\kappa} \epsilon^{\alpha_\epsilon} S_{cr}^{\alpha_S} M^{\boxed{\alpha_M}}$$



Yan 2017, DIII-D

- Confinement time scales with the ion mass with the exponent of $\alpha_M$ = 0.08-0.5.
- The H-mode power threshold is significantly reduced on D plasmas.

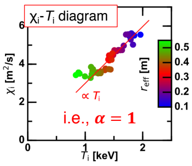
**Isotope effect is much clearer in structure formation property than the energy confinement time in tokamaks.**

*In this contribution, we investigate isotope effects in the confinement structure formation property in LHD by focusing upon* ***internal transport barriers (ITBs)***

## Profile gain factor as indicator of the ITB intensity

Dome-shape profile $\chi = kT^\alpha,\ \alpha > 0$

$$0 = \frac{1}{r}\frac{\partial}{\partial r}(rq) + P, \quad q = -n\chi\frac{\partial T}{\partial r} \qquad (1)$$



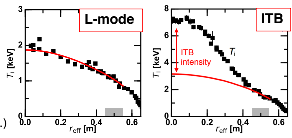
- Solve Eqs. (1) numerically with measured *n* and *P*.
  → $T_i$ that follows the L-mode scaling.
- *k* is given at the edge, where the confinement behaves as the L-mode even when the ITB is formed.

Solution of Eqs. (1) :

L-mode reference profile $T_{\mathrm{i,L}}^{\mathrm{ref}}$

➢ Profile gain factor as an ITB intensity is defined as

$$G_\alpha = \frac{\int nT_{\mathrm{i}}rdr}{\int nT_{\mathrm{i,L}}^{\mathrm{ref}}rdr} \quad \text{(Scalar coef.)}$$



T. Kobayashi+, Plasma Phys. Control. Fusion **61** 085005 (2019)

## Isotope effects in the ITB intensity

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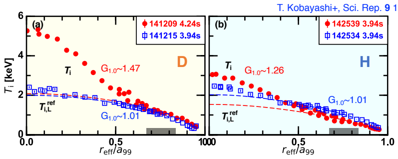
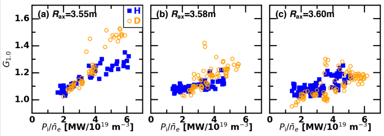


① **Stronger ITB in D.**
② **ITB-concomitant edge confinement degradation in H.**



The isotope effect is clearer in the inward shifted configuration.

## Isotope effects in the ITB intensity

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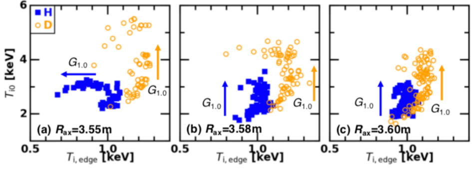

- Core and edge ion temperatures are plotted for all the dataset.
- In H plasmas with $R_{ax}$ = 3.55 m, the edge ion temperature decreases as the ITB becomes stronger.

➢ **ITB-concomitant edge confinement degradation in H.**

c.f. core-edge coupling

## What determines the ITB intensity?

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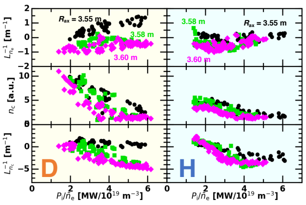
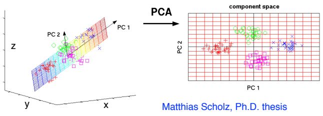


By varying $\bar{n}_e$, multiple parameters, i.e., $n_c$, $L_{nc}^{-1}$, and $L_{ne}^{-1}$ change simultaneously.

➢ These parameters are considered to be important for ITB formation.

Tokar+, PPCF (1999), Osakabe+, PPCF (2014), Ida+ NF (2019).

➢ To decompose interrelation among them, Principal Component Analysis (PCA) is performed.



Matthias Scholz, Ph.D. thesis

Define new dimensions

➢ Data can be expressed with reduced number of dimensions: PC1 and PC2 without losing much of information.

## Results of PCA

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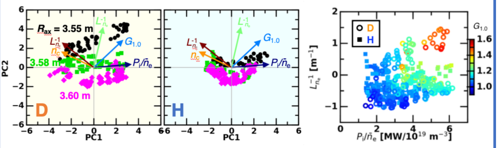
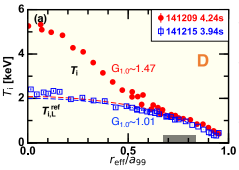


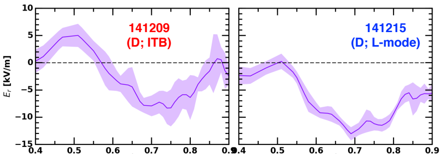
- PCA is performed for 5-dimensional data in ($P_i/\bar{n}_e$, $G_{1.0}$, $n_c$, $L_{nc}^{-1}$, $L_{ne}^{-1}$).
- Approximately 90 % of the information in the dataset can be represented by the 1st and 2nd PCs.
- $G_{1.0}$ correlates with $P_i/\bar{n}_e$ and $L_{ne}^{-1}$, while little correlates with $n_c$ and $L_{nc}^{-1}$.

➢ Peaked density profile in low density D plasmas may play a role.

## Role of the radial electric field on the ITB intensity



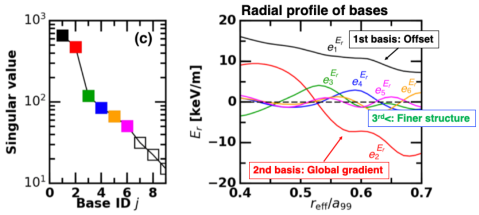
- Radial electric field is measured by CXS.
- The $E_r$ profile shapes are similar regardless of the ITB formation.
- A negative offset exists in the L-mode.



## Singular Value Decomposition (SVD) for radial electric field

- Radial decomposition: Fourier basis may not be appropriate.
- For heuristic decomposition, SVD is used.

SVD: signal decomposition by bases driven by data.

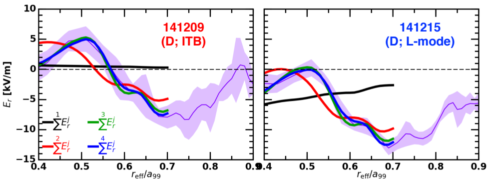


## Singular Value Decomposition (SVD) for radial electric field

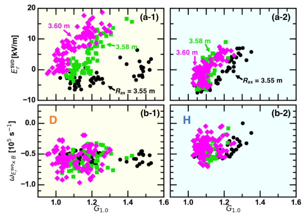
Data reconstruction:
(Linear combination)

$$E_r(r) = \sum_{j=1}^{n} \underline{a_j}\,\underline{V_j(r)}$$

Amplitude
Bases



## Role of ExB shear on the ITB strength



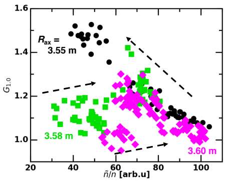
$$E_r^{\mathrm{SVD}}(r) = \sum_{j=1}^{2} a_j V_j(r)$$

Correlation between the ITB strength and the higher order $E_r$ components is negligible.
→ Omitted.

- The radial electric field clearly increases as the ITB strength raises, although the different magnetic axis conditions and ion species have different tendencies.
- The E × B shearing rate seems not to depend on the ITB strength
- The E × B shearing rate is systematically less than the linear growth rates of the ITG instability of γ ~ $10^5$ $s^{-1}$.

➢ Meaning that the E × B shearing plays a minor role on the turbulence stabilization and the ITB formation.

## Relation between the turbulence amplitude and the ITB strength



- Direct evaluation of the turbulent heat flux ($q_i \propto k_\theta n\langle\tilde{\phi}\tilde{T}_i\rangle + k_\theta T_i\langle\tilde{\phi}\tilde{n}\rangle$) is difficult.
- As a (imperfect) proxy of the turbulent transport, $\tilde{n}$ measured by PCI is used.
- PCI data were operated only in D cases.

- Relative density fluctuation amplitude $\tilde{n}/n$ are integrated in space and wavenumber.
- There are turning points in the turbulence amplitude evolution likely due to ITB formation:
  When $G_{1.0}$ is small, $\tilde{n}/n$ increases with $G_{1.0}$
  When $G_{1.0}$ is Large, $\tilde{n}/n$ decreases with $G_{1.0}$

## Summary

1. What kind of isotope effect exists in ITB intensity?
   - Stronger ITBs are formed in the deuterium plasmas.
   - An ITB concomitant edge confinement degradation emerges in the hydrogen plasmas.
   - Principal component analysis reveals that the ion ITB becomes strong when a high input power normalized by the line averaged electron density is applied and electron density profile is peaked.
2. What is the role of the radial electric field?
   - Electric field shear is almost constant regardless of the ITB intensity.
   - Shearing rate (~$10^5$ $s^{-1}$) of the electric field is one order of magnitude smaller than the linear growth rate.
   - ➢ $E_r$ shear may not play a role.
3. What is the role of the turbulence?
   - Density fluctuation amplitude is suppressed when the ITB is formed.