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# Turbulent Properties Against Hydrogen Isotope Ratio and Zonal Flow Activities in Heliotron J

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## ABSTRACT

The properties of turbulence and turbulent transport against the variation of isotope ratio and zonal flow activity are elucidated in Heliotron J.

The turbulence amplitudes for density and potential fluctuations reduce as the hydrogen/deuterium(H/D) gas ratio is varied from H to D dominant plasmas and zonal flow activity is enhanced. Two-point correlation analysis reveals that the correlation of the fluctuations decreases in D plasmas, although the turbulence scale size increases as D gas fraction increases. A statistical analysis using a joint probability density function technique also indicates that the density and potential fluctuations are decoupled in D plasmas, which should contribute to the suppression of turbulence-driven transport and the confinement improvement in D plasma. Furthermore, fluctuation-induced particle flux reduces clearly as the D gas content is dominated.

These observations suggest that the isotope effect can emerge through the suppression and decoupling of density/potential fluctuations and the reduction of fluctuation-induced particle flux, which is attributed to the enhanced zonal flow activity in D plasmas observed in the experiment.

## Background and Motivation

**Isotope effect is a well-established evidence, BUT cannot be explained by primitive model of transport**

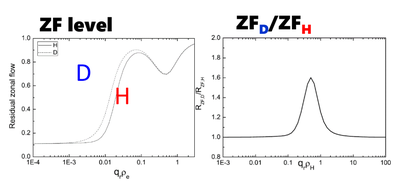
- ✓Turbulence diffusivity : $D \sim L_c^2/\tau_c$ (based on a random walk model)
- ✓Correlation length ~ Larmor radius ($\rho_i$) ~ ion mass ($m_i$)

Heavier ion mass
→ Larger turbulence scale→ Worse transport!! ***Not consistent with isotope effect***

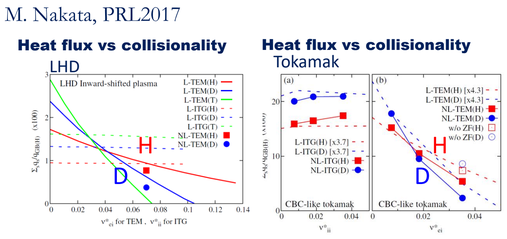
**Zonal flow is a possible mechanism to explain the emergence of Isotope effect**

***Theory***

T.S. Hahm NF 2013



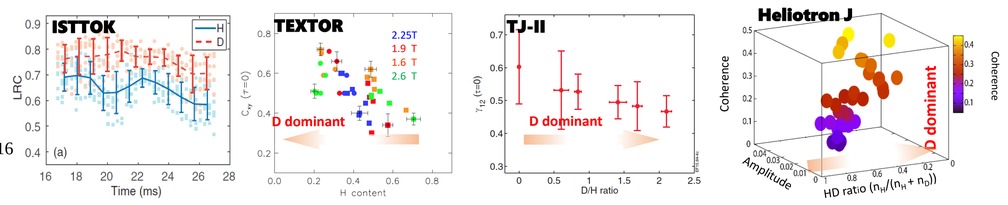

M. Nakata, PRL2017







***EXP.***




B Liu et al, NF. 2016
Y. Xu, PRL. 2013
B Liu et al, NF. 2015
S. Ohshima IAEA 2016

***However, we are not sure how enhanced ZF in D plasma modify turbulence and the resultant transport in experiment***

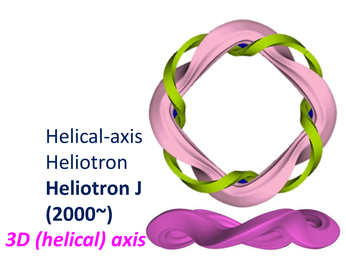
**What we assessed in this experimental study**

- ✓ How do fluctuation characteristics and fluctuation-induced transport respond to the isotope ratio and enhanced zonal flow activity?

→Turbulence correlation length, correlation between density and potential fluctuations, statistical characteristics, and fluctuation-induced particle flux were assessed.

## Experimental Set up & zonal flow activity in Heliotron J

➢ **Heliotron J device**

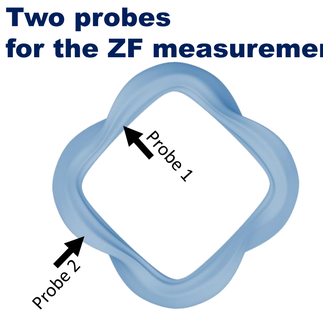



- ◆ Major Radius : R=1.2 m
- ◆ Plasma Major/Minor Radius : R/a = 1.2m / 0.1-0.2 m
- ◆ Magnetic Field : B≦1.5 T
- ◆ Heating system : ECH, NBI, ICRF

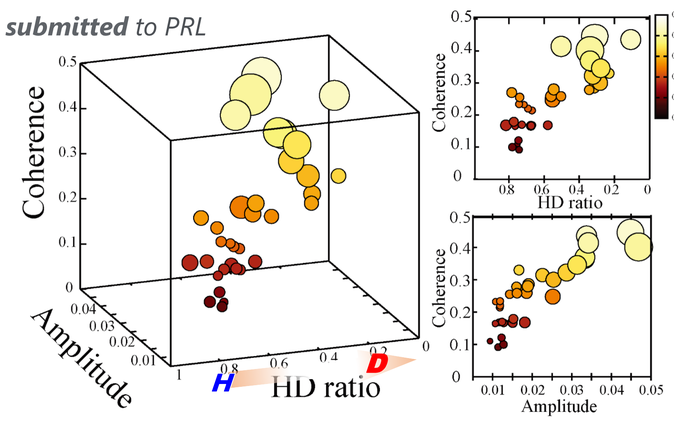
Typically,
Te(0) > 1 keV, Ti(0) > ~100-300 eV @ ne~ 1 x $10^{19}$ $m^{-3}$

**Isotope effect of zonal flow in Heliotron J**

➢ **Two probes for the ZF measurement**



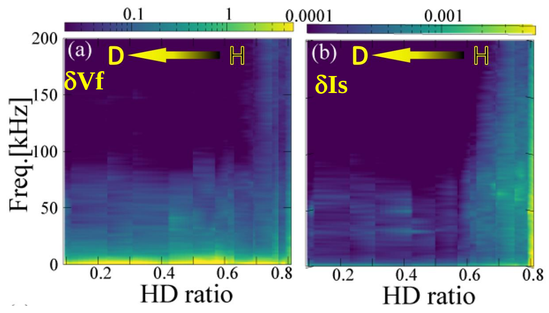

*submitted to PRL*



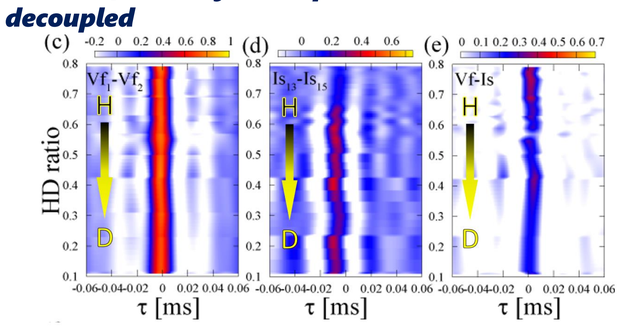

## Isotope dependence of turbulence and turbulent transport

### ➢ Isotope dependence of turbulence properties

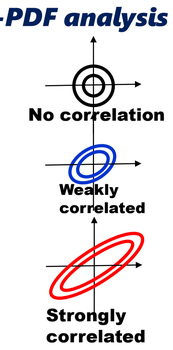
✓ ***Fluctuation level increase in H***

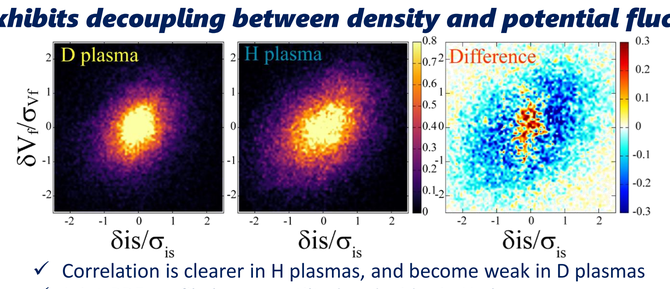



✓ ***Correlation length of fluctuation increases in D, however, density and potential fluctuations are decoupled***




✓ ***Joint-PDF analysis exhibits decoupling between density and potential fluctuation in D***



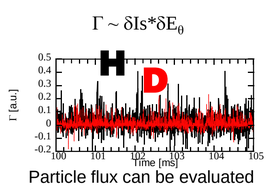

*submitted to PRL*

- ✓ Correlation is clearer in H plasmas, and become weak in D plasmas
- ✓ Joint-PDF profile becomes tilted and wider in H plasmas
  - →Density and potential fluctuations are more decorrelated in D plasmas
  - → Spikes/Pulses should contribute the change of PDF profil (skewness and kurtosis is different)

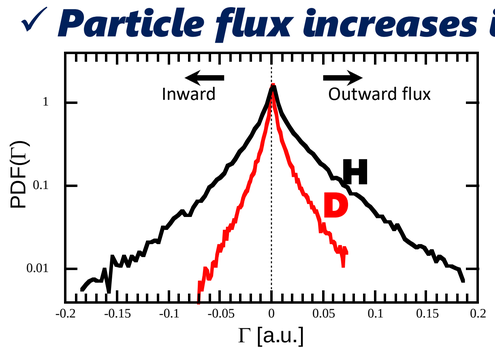
### ➢ Fluctuation-induced particle flux

✓ ***Particle flux increases in H***

$\Gamma \sim \delta Is * \delta E_\theta$

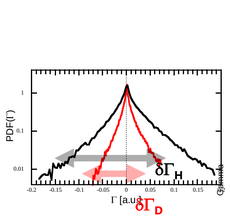


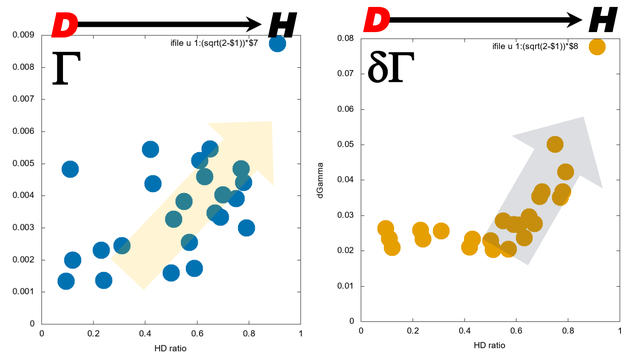

Particle flux can be evaluated from the probe measurement



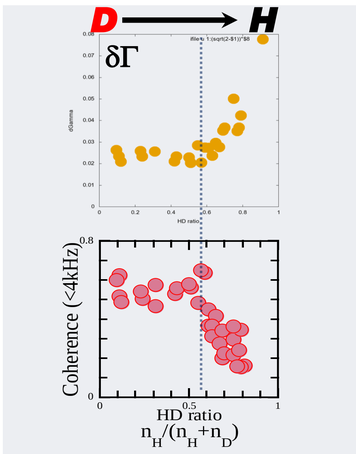

- ✓ Fluctuation-induced particle flux Γ is in outward direction
- ✓ Particle flux PDF is strongly modified against the HD ratio
- ✓ <Γ> in D plasma is smaller than in H plasma
- ✓ dΓ is also smaller in D plasma

✓ ***Particle flux exhibits isotope dependence***



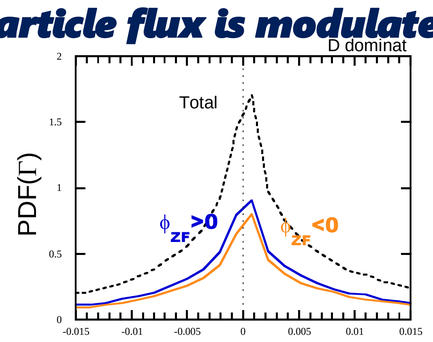




- ✓ Fluctuation-induced particle flux Γ is in outward direction
- ✓ <Γ> increase systematically against the H content




- ✓ The particle flux fluctuation(δΓ) is well correlated with the correlation amplitude of of ZF and the HD ratio.

✓ ***Particle flux is modulated by ZF***

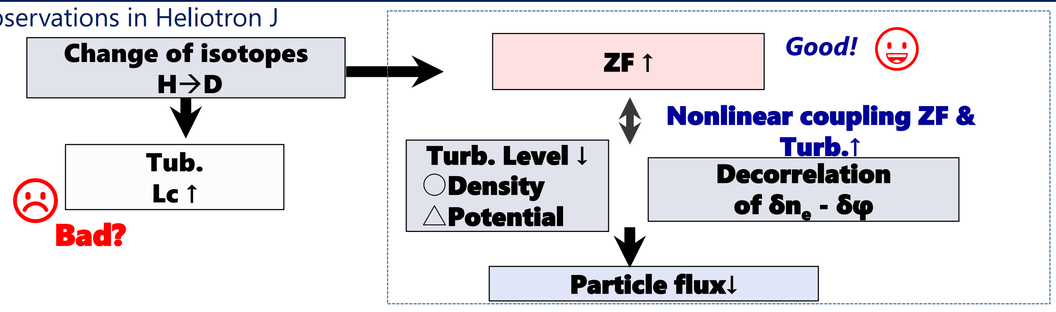



- ✓ Particle flux PDFs are plotted against the cases of ZF potential is positive/negative
- ✓ PDFs are different each other

→A clear evidence that ZF modify turbulence-driven transport

## CONCLUSION

・Observations in Heliotron J




- ✓Turbulence characteristics are modified by enhanced ZF in D plasmas
- ✓Reduction of fluctuation level and decorrelation between density & potential fluctuations suppress fluctuation-induced particle flux in D plasmas

***Note: Very low-density experiment. Not sure for higher density regime***

Measurement of one quantity (e.g. density) might not be enough to understand isotope effect. Correlation between different quantities, nonlinear characteristics, statistical characteristics should be assessed from the viewpoint above

## ACKNOWLEDGEMENTS

PLADyS
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