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Rotation Reversal and Intrinsic Rotation Characteristics in KSTAR Ohmic Plasmas

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Contents

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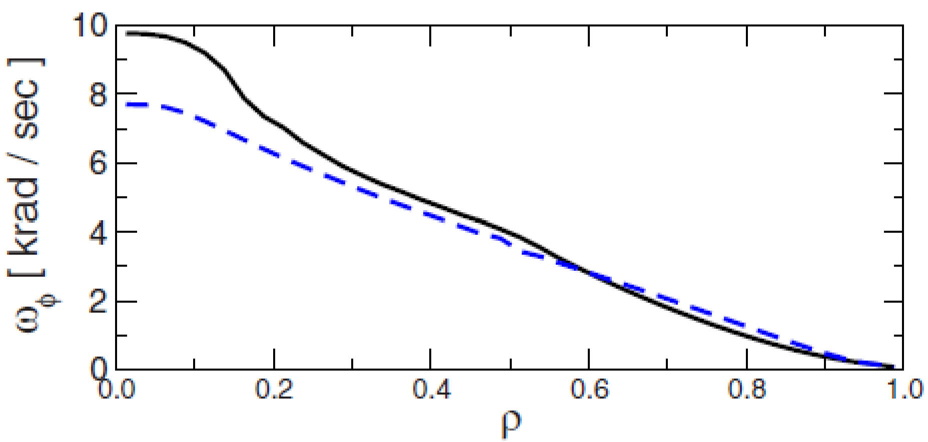
Introduction

- **Toroidal rotation has beneficial effects on stability and confinement**
  - **Resistive Wall Mode, TM stabilization/Prevention of Mode Locking**
  - **Suppression of turbulence**
- **However, the external torques to drive the toroidal rotation are expected to be limited to low levels for future devices**



[Federico D Halpern et al 2008 PoP]

ITER prediction using 30 MW of NBI heating

GLF23 (solid line), MMM95 (dashed line)

Much smaller than the conventional beam plasmas

➢ **Intrinsic rotation has drawn an attention in recent research**

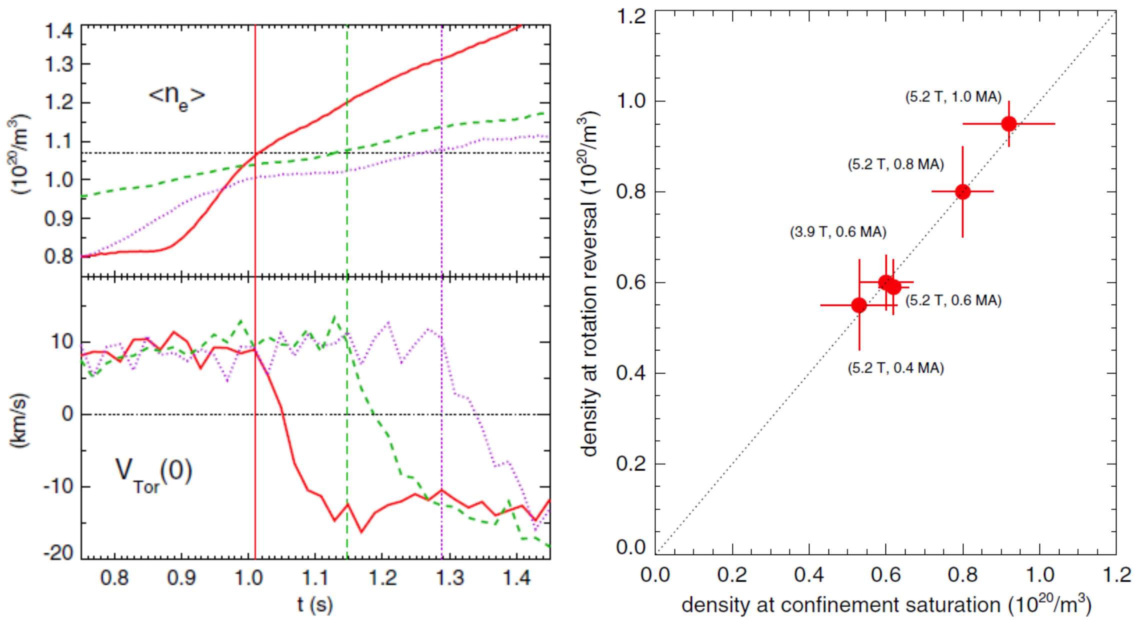
What is Rotation Reversal?

▪ Rotation reversal is one of the intrinsic rotation phenomena.

▪ In various devices, an abrupt sign change of the core intrinsic rotation, which is referred to as a rotation reversal, is observed during a ramp-up of the electron density and the collisionality in Ohmic L-mode plasmas.

▪ Rotation reversal looks coincide with the critical density of the LOC/SOC transition

Alcator C-Mod



[Rice J E et al 2011 Nucl. Fusion]

✓ Sign flip of the residual stress with the LOC/SOC transition has been considered as a possible mechanism.

✓ It triggers an interest in the coherence b/w the intrinsic rotation and the turbulence.

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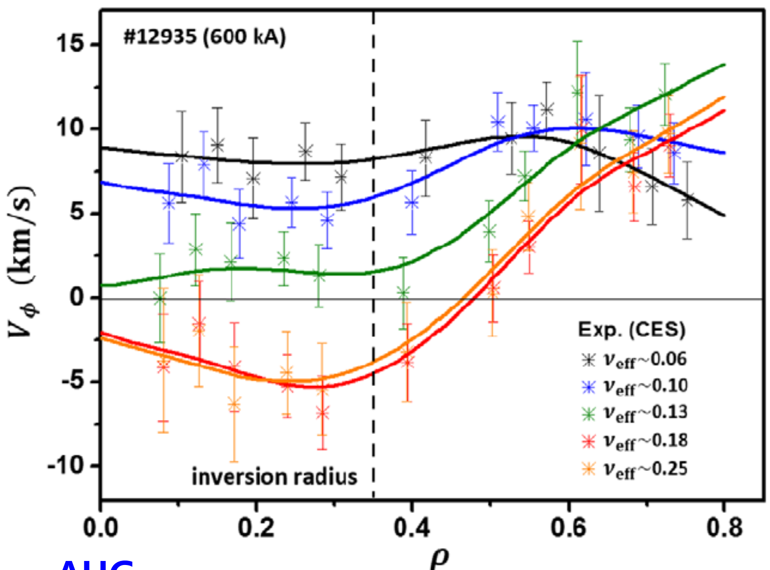
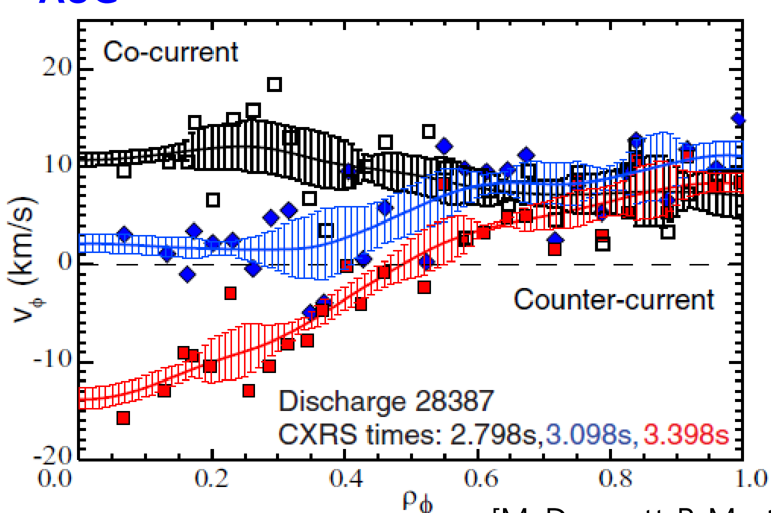
Observation of Rotation Reversal in KSTAR

KSTAR



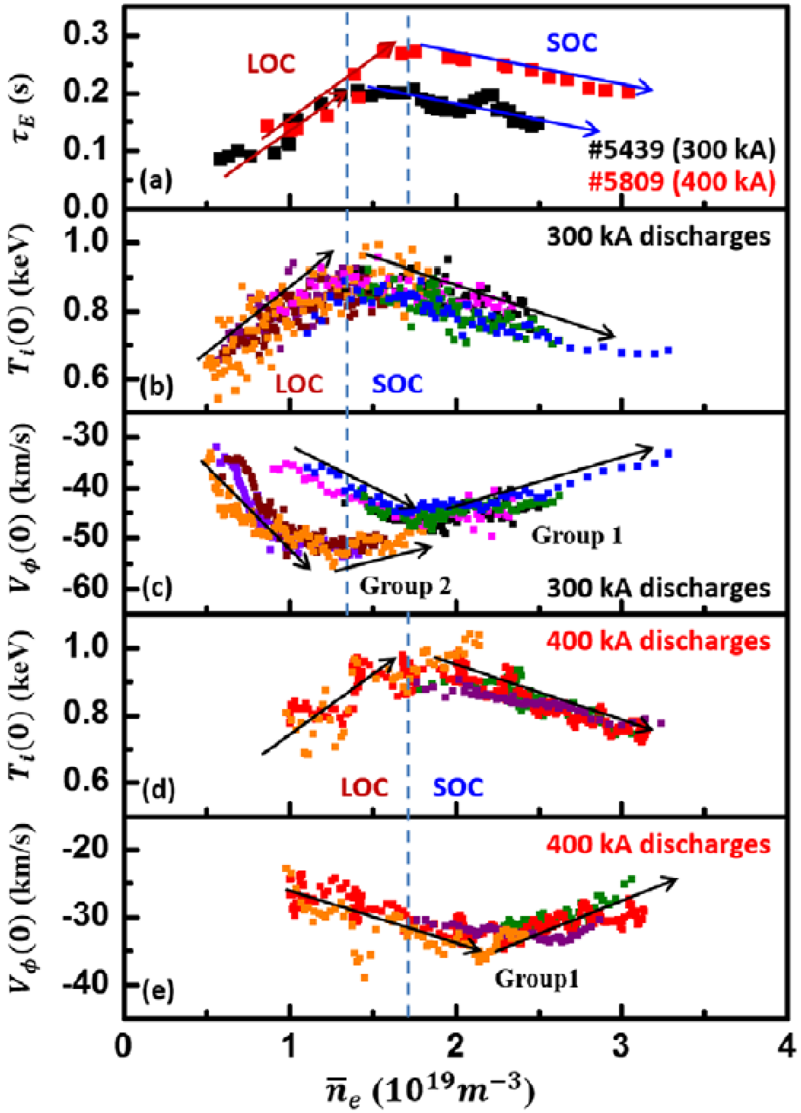
AUG



[McDermott R M et al 2014 Nucl. Fusion]

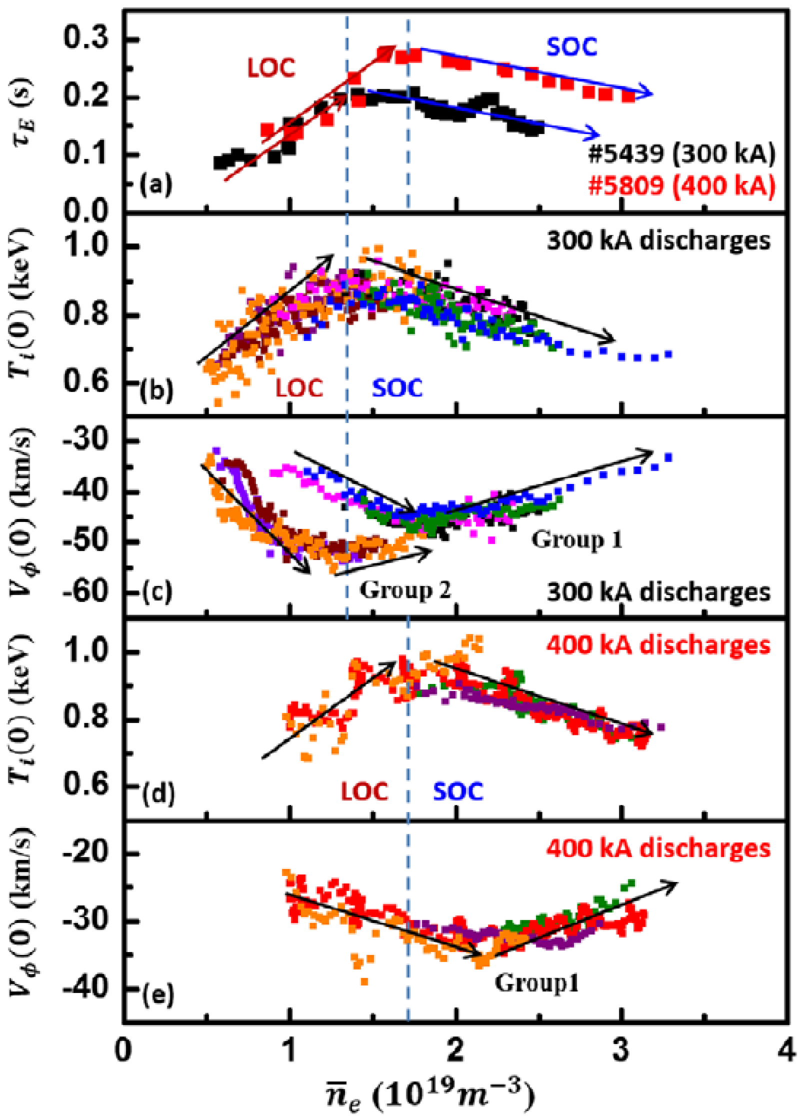
- **In KSTAR, the rotation reversal was observed in Ohmic discharges with the density ramp-up.**
- **Sign of the core toroidal rotation is reversed from co- to ctr-direction.**
- **Rotation reversal in KSTAR occurs near the LOC/SOC transition.**
- **Main change in the rotation profile during the rotation reversal is a rotation gradient change in a local region ($0.3 < \rho < 0.7$).**
- **Anchor point, a kind of core boundary is observed.**
  - ➢ **Similar characteristics with other devices (AUG, Alcater C-Mod) are observed.**

Intrinsic rotation behaviour in KSTAR

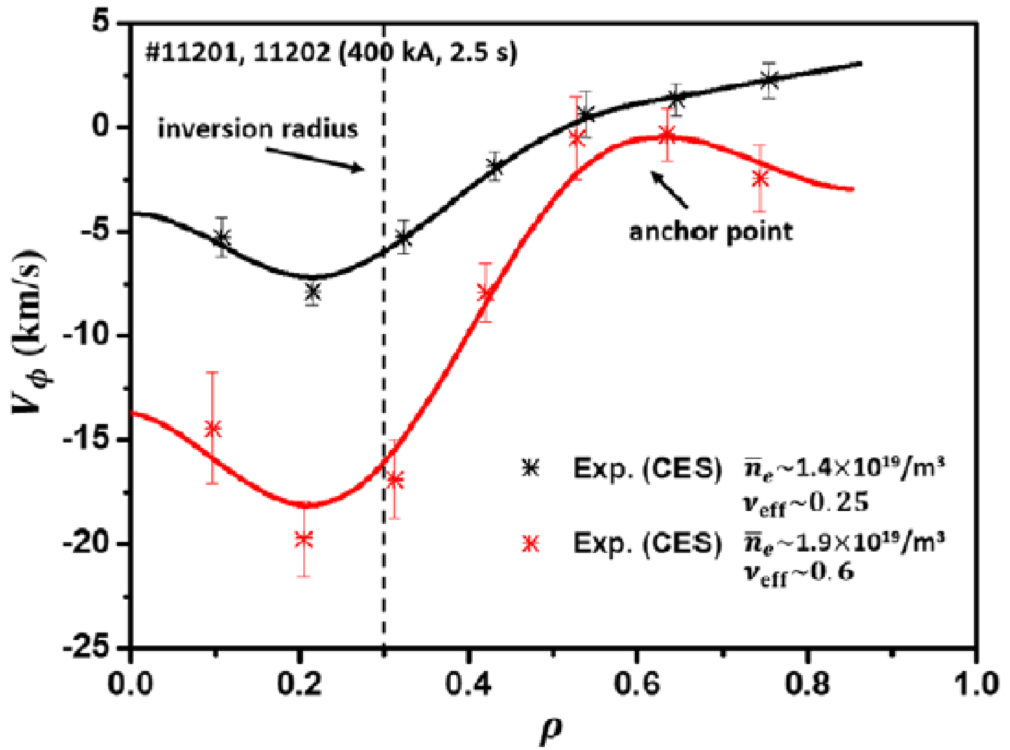


- Global behaviour of the core intrinsic rotation and the core ion temperature near the LOC/SOC transition was figured out based on the KSTAR database.
- Core ion temperature shows a correlation to the energy confinement time (increase/decrease, before/after the LOC/SOC transition).
- Core intrinsic rotation increases in the counter-direction with a density ramp-up before reaching a specific density, but above this, the core intrinsic rotation increases in the co-direction (It is not exactly same to the LOC/SOC transition).
- No clear signature of the rotation reversal has been detected in this database, even with a clear transition of LOC/SOC.

Intrinsic rotation behaviour in KSTAR – cont.



- Core intrinsic rotation behaviour relates with the u′ change in a local region. $(u' \equiv -R\nabla V_\phi / v_{th,i})$

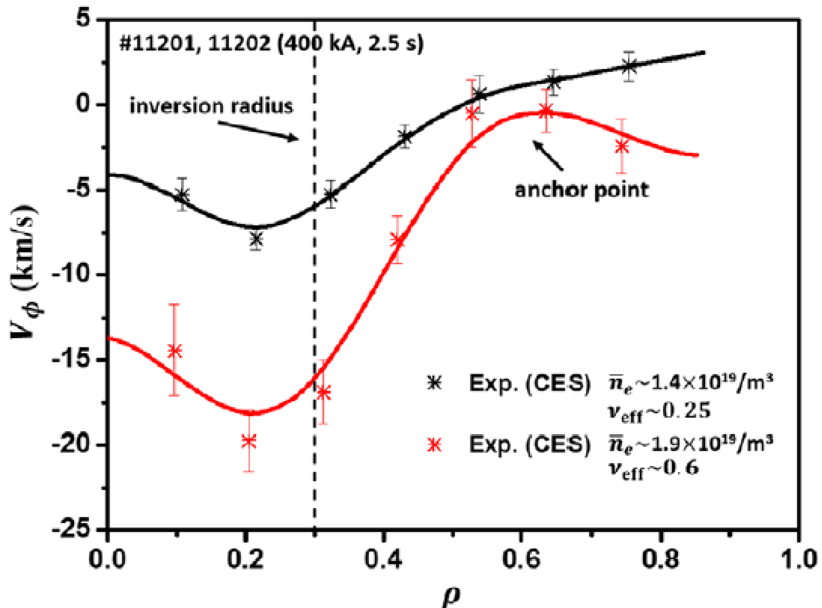


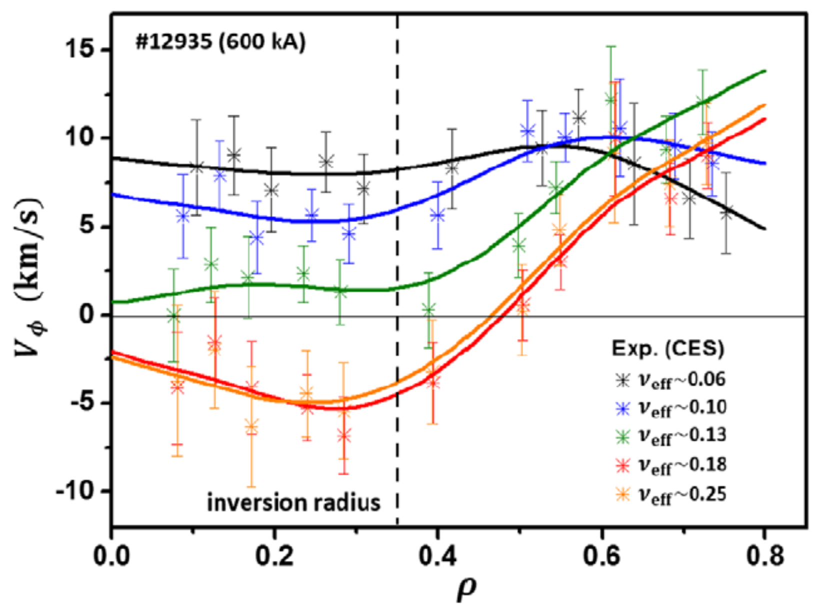
Rotation Reversal? or u′ change?

- u′ change is observed with a density ramp-up regardless of the rotation reversal.

- Comparison between u′ change and rotation reversal

u′ change vs **Rotation reversal**

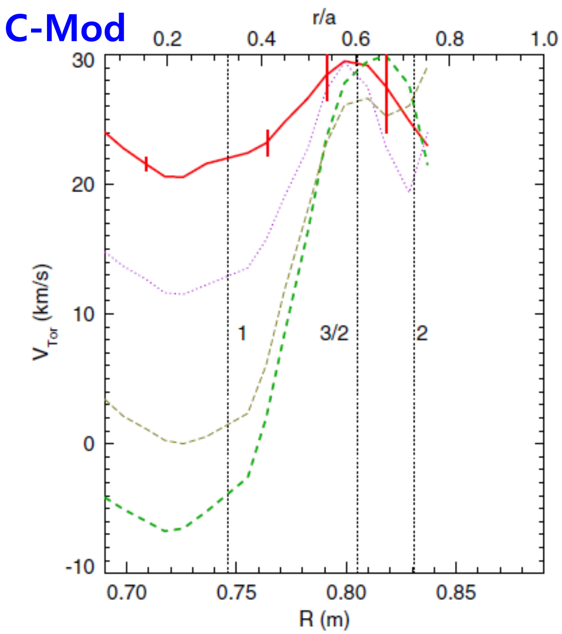


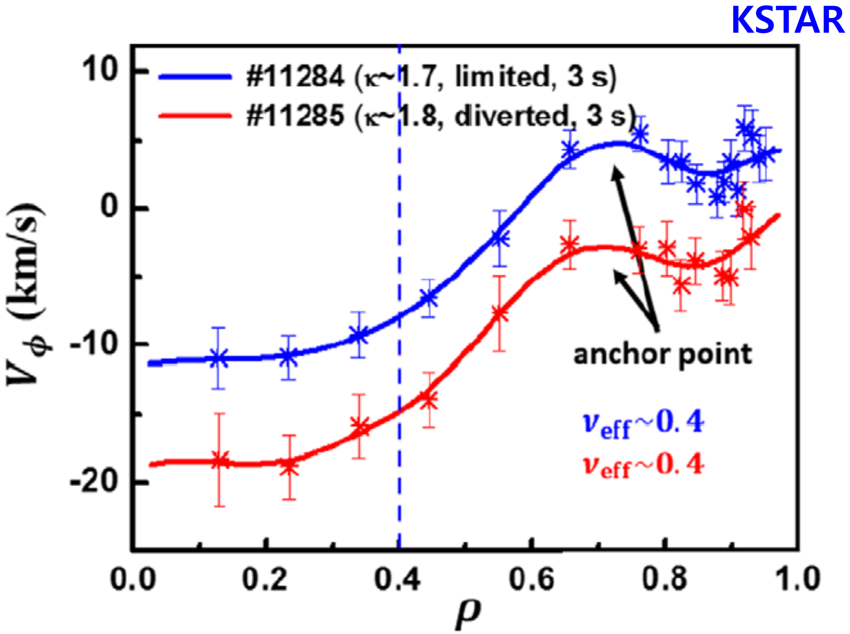


- In both cases
  - Gradient of the toroidal rotation changes with the density in a local region.
  - Rotation at ρ ~ 0.6-0.7, so called anchor point, plays as a boundary.

➢ Main difference is the value of the toroidal rotation at the anchor point.

Rotation Reversal? or u′ change? – cont.





- In Alcator C-Mod, it was briefly reported that the location of the anchor point seems to correlate with the q~3/2 surface.

- In KSTAR, the location and the value of the toroidal rotation at the anchor point could change with various parameters (Ip, Bt, Elongation, Limited/Diverted).

- When the rotation at the anchor point have a co-directed rotation, the rotation reversal could occur as a result of combination of the u′ change and the co-rotating anchor point in KSTAR.

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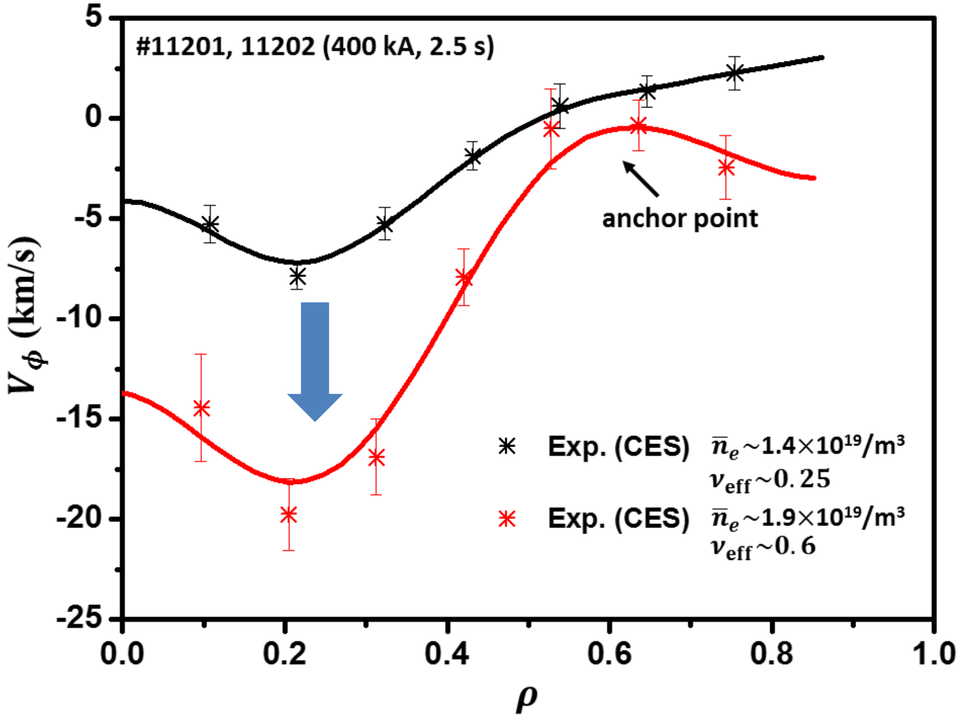
Decomposition of torque and fluxes

▪ The intrinsic rotation behavior results from the interplay between the intrinsic torque and the momentum flux in momentum transport.



▪ **What makes u′ change?**

✓ Increase of counter torques?

✓ Decrease of momentum fluxes?

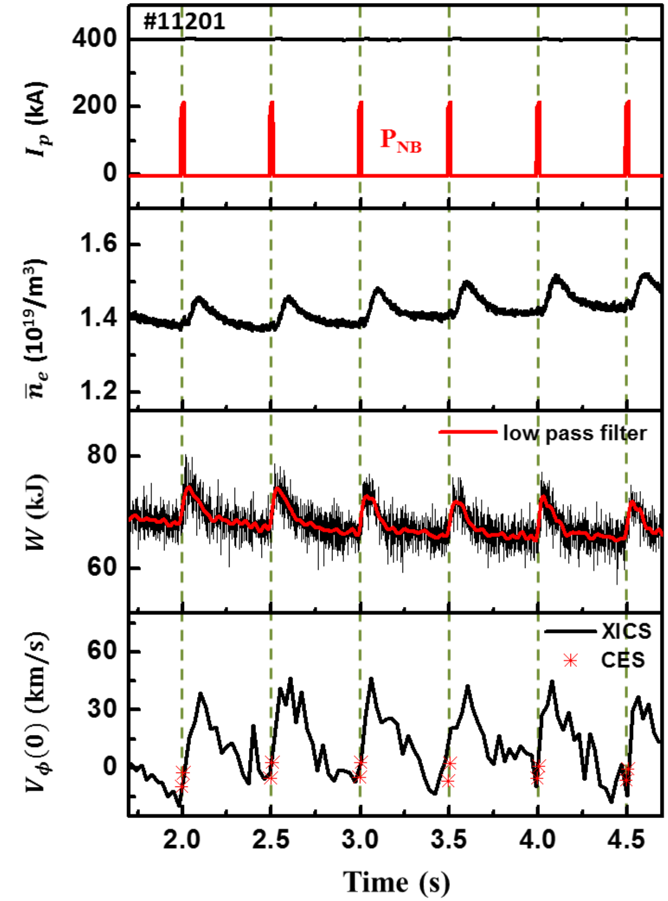
✓ Interplay between them?

▪ To understand the underlying physics of the intrinsic rotation behaviour, **it is important to decompose the intrinsic torque and the momentum fluxes.**

Perturbative analysis using beam blip experiments

- Using dual measurement systems of XICS and CES in KSTAR, perturbative analysis was performed in Ohmic plasmas with the following assumptions.

  - No variations in χ_ϕ and RV_p/χ_ϕ during the beam blip perturbation (no big change in n, T).
  - Radially constant χ_ϕ and RV_p/χ_ϕ (or possible profiles such as $\chi_\phi \propto \chi_i$)
  - Neglecting the effect of sawtooth



- Torques from the beam blips are calculated by using NUBEAM and the angular momentum equation is solved by using ASTRA by implementing the Reynolds stress term

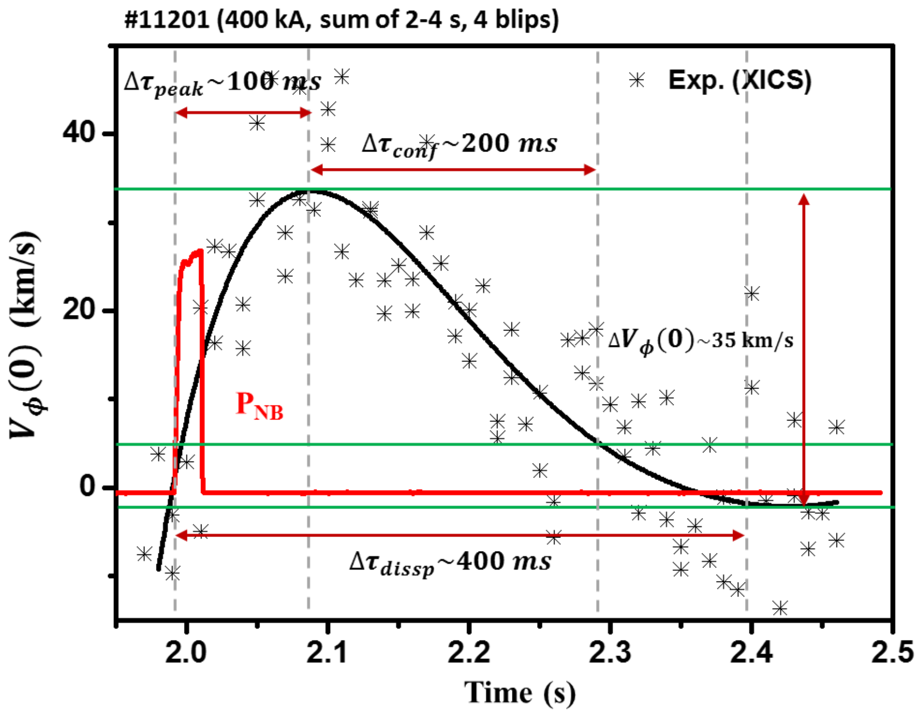
$$\frac{\partial L_\phi}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(r\Pi_\phi) = \sum \tau_\phi \qquad (\sum \tau_\phi \text{ : sum of the external torques })$$

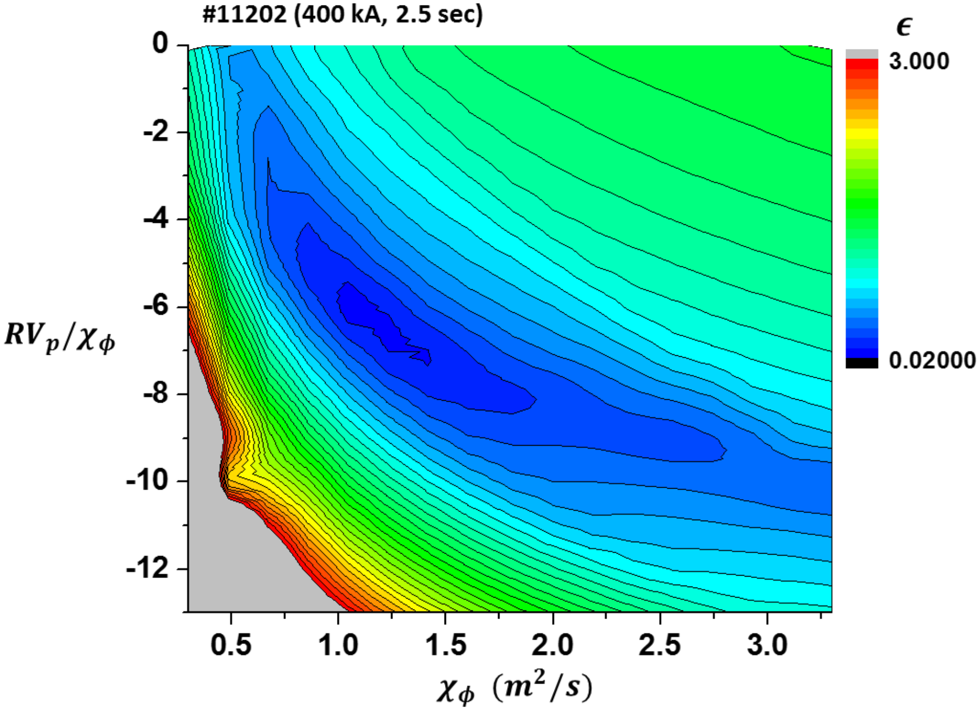
$$\Pi_{res} \equiv \chi_\phi \frac{\partial L_{\phi,init}}{\partial r} - V_p L_{\phi,init}$$

$$\Pi_\phi = \underbrace{-\chi_\phi \frac{\partial L_\phi}{\partial r}}_{\text{Momentum diffusion term}} + \underbrace{V_p L_\phi}_{\text{Momentum pinch or Convective term}} + \underbrace{\Pi_{res}}_{\text{Residual stress term}}$$

$$(\tau_{intrinsic} \equiv -\nabla \cdot \Pi_{res})$$

Initial results of perturbative analysis





- ✓ Beam blip was applied for 20 ms which results in increase of the core toroidal rotation and it reaches the maximum value in about 100 ms. Then, the core toroidal rotation gradually decreases for 300 ms down to the level before the beam blip was applied.
- ✓ Phase & amplitude information can be taken from the experiment to decompose each terms.
- ✓ From coefficient scanning in the transport simulation, the best matching value of chi_phi and pinch can be obtained.

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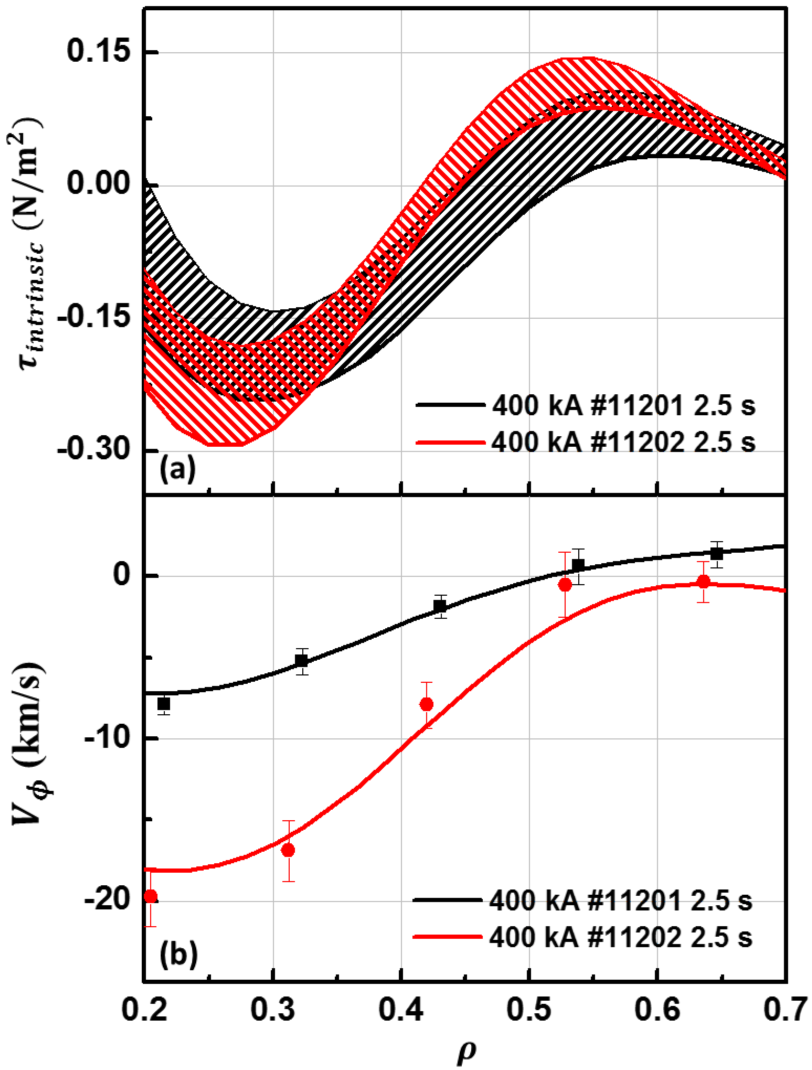
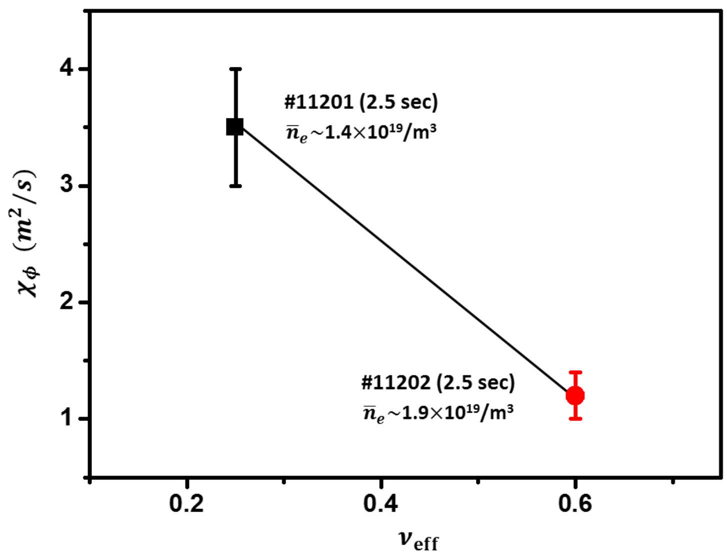
u′ change: $\tau_{intrinsic}$ vs momentum transport





✓ Decrease of χ_ϕ seems to be more dominant than the change of $\tau_{intrinsic}$ to explain the u′ change (opposite direction of change in χ_ϕ vs χ_ϕ^{NC}).

✓ Initial results imply

χ_ϕ decreases with the collisionality increase

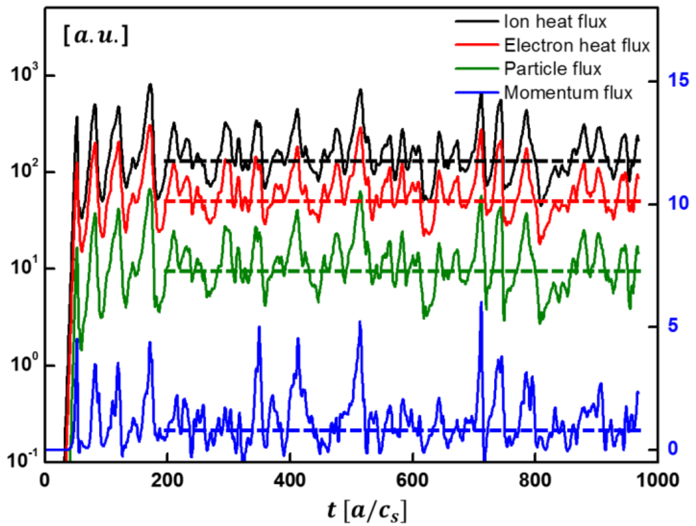
⬇

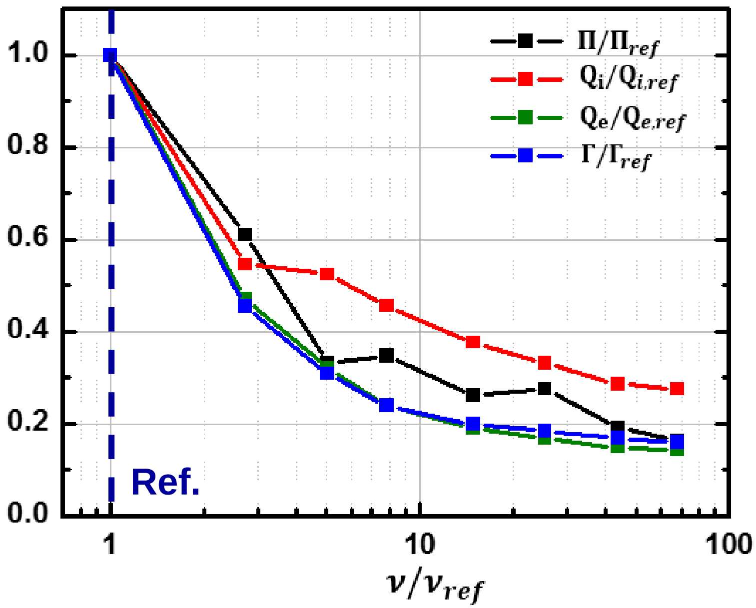
u′ change

⬇

If a proper anchor point is given, rotation reversal

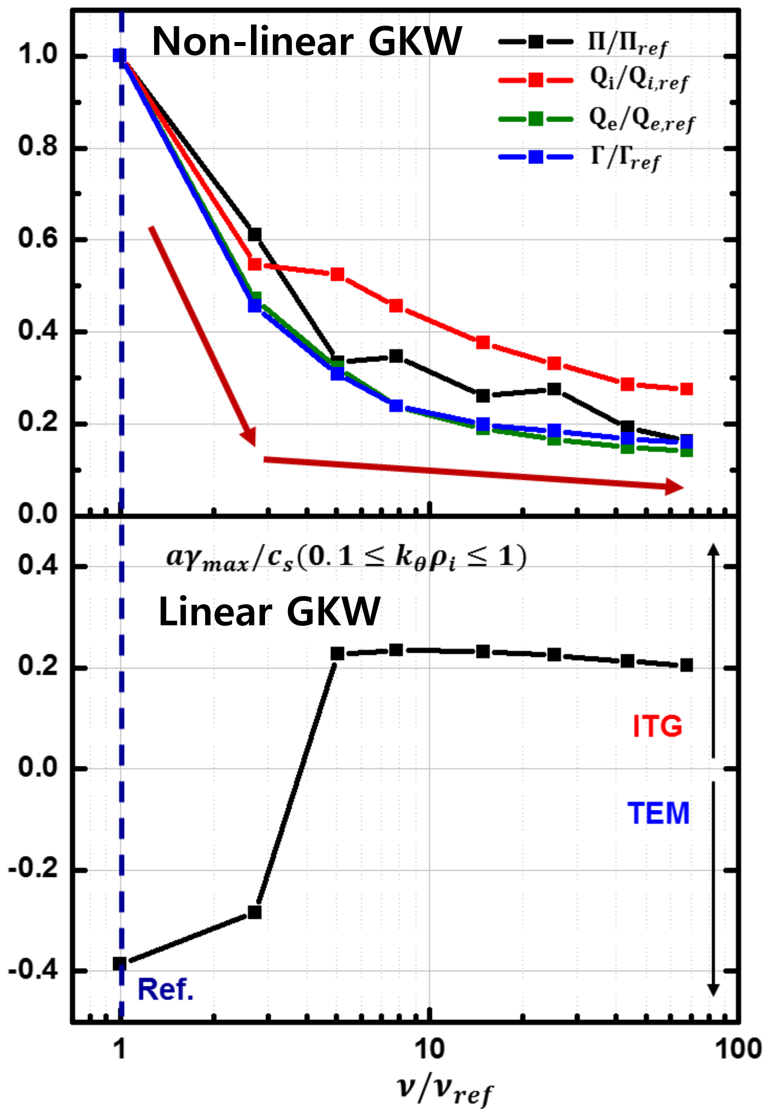
Turbulent transport characteristics from gyrokinetics





- Local non-linear gyrokinetic calculation was performed with GKW to evaluate the momentum diffusion variation with the collisionality.
- Calculation was performed at r/a=0.5 (u' change is localized at 0.3 < r/a < 0.7).
- By averaging over the time interval, turbulent fluxes can be obtained.
- All fluxes (particle, ion and electron heat, and momentum) are found to decrease with respect to the collisionality.

Turbulent transport characteristics from gyrokinetics



- **Notable characteristic is:**
  At a low collisionality, the fluxes decrease more drastically rather than at a high collisionality.

- **Linear GKW calculation is carried out to check if the most dominant micro-instability varies with the collisionality.**

- **In the TEM dominant regime, the fluxes decrease rapidly with respect to the collisionality. As the collisionality increases, the ITG mode can be most dominant and the decrease of fluxes is reduced.**

- **The change of the flux according to change of the dominant mode could affect u'.**

➢ **This GK simulation result could explain the variation of u' as changing the collisionality in KSTAR experiments.**

Conclusions

- **Rotation reversal was observed in KSTAR Ohmic plasmas and its characteristics were investigated by perturbative transport analysis and linear/non-linear GK simulations.**

- **Based on the KSTAR Ohmic discharge database, it was suggested that the rotation reversal could be a combination of the u′ change and the co-rotating anchor point (the sign of the core rotation is not important).**

- **Initial transport analysis results imply that the u′ change with the collisionality could mainly result from the change of the momentum diffusion rather than the change of the intrinsic torques.**

- **Non-linear gyrokinetic calculation shows a reduction of the momentum flux as the collisionality increases which agrees with the experimental observation. Linear gyrokinetic analysis suggests that as the dominant mode changes the behaviour of the momentum flux change can be different.**

Backup - Unanswered questions / Future works

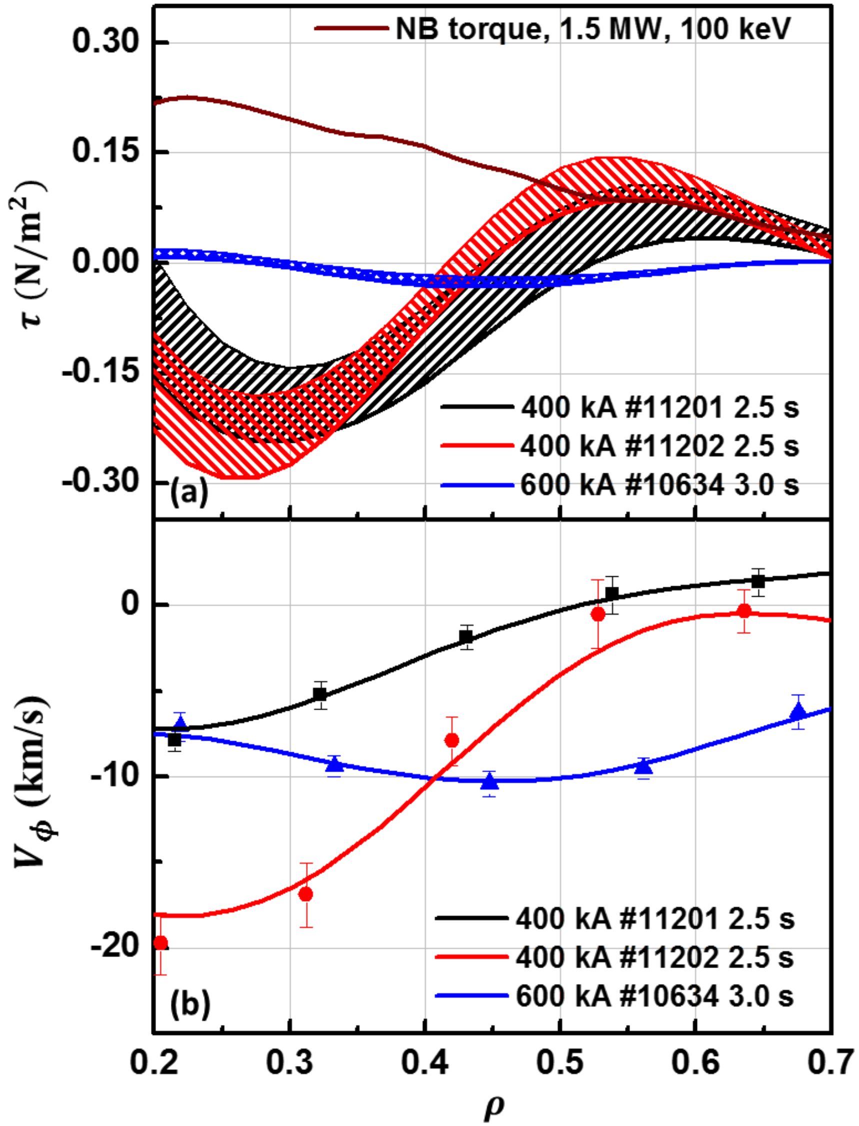
Unanswered questions

- Turbulent momentum fluxes due to the TEM/ITG mode?
- What determines the anchor point?
  Radial distribution of the intrinsic torque profile?
- Magnitude of the intrinsic torque and its dependence?

Future works

- More systematic analysis for the momentum transport based on a large database
- Quantitative comparison between the experimentally calculated fluxes and the turbulent fluxes from the gyrokientics in entire region
- Comparison to the fluctuation characteristics from ECEI and MIR

Backup - Intrinsic torques characteristics



Calculated intrinsic torque at a low plasma current is comparable to the single beam torque!

Existence of the anchor point can be a clue for the radial distribution of the intrinsic torque (co & ctr)