Finite-Collisionality Generalization of the Heuristic Drift Model of SOL

&

Implications for Shear Flow Stabilization of SOL Interchange Turbulence

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ASDEX Upgrade

Generalizing the HD Model → GHD Model

- Original "low-gas-puff" HD Model assumed convective-like losses from SOL, but upstream T_e determined by Spitzer-Härm diffusion.
- To generalize for finite collisionality, must include parallel thermal resistance + effect of target $T_e = T_t$ on upstream $T_e = T_u$.
- Use the SOL parallel energy confinement time to define $\lambda_{q,GHD}$:

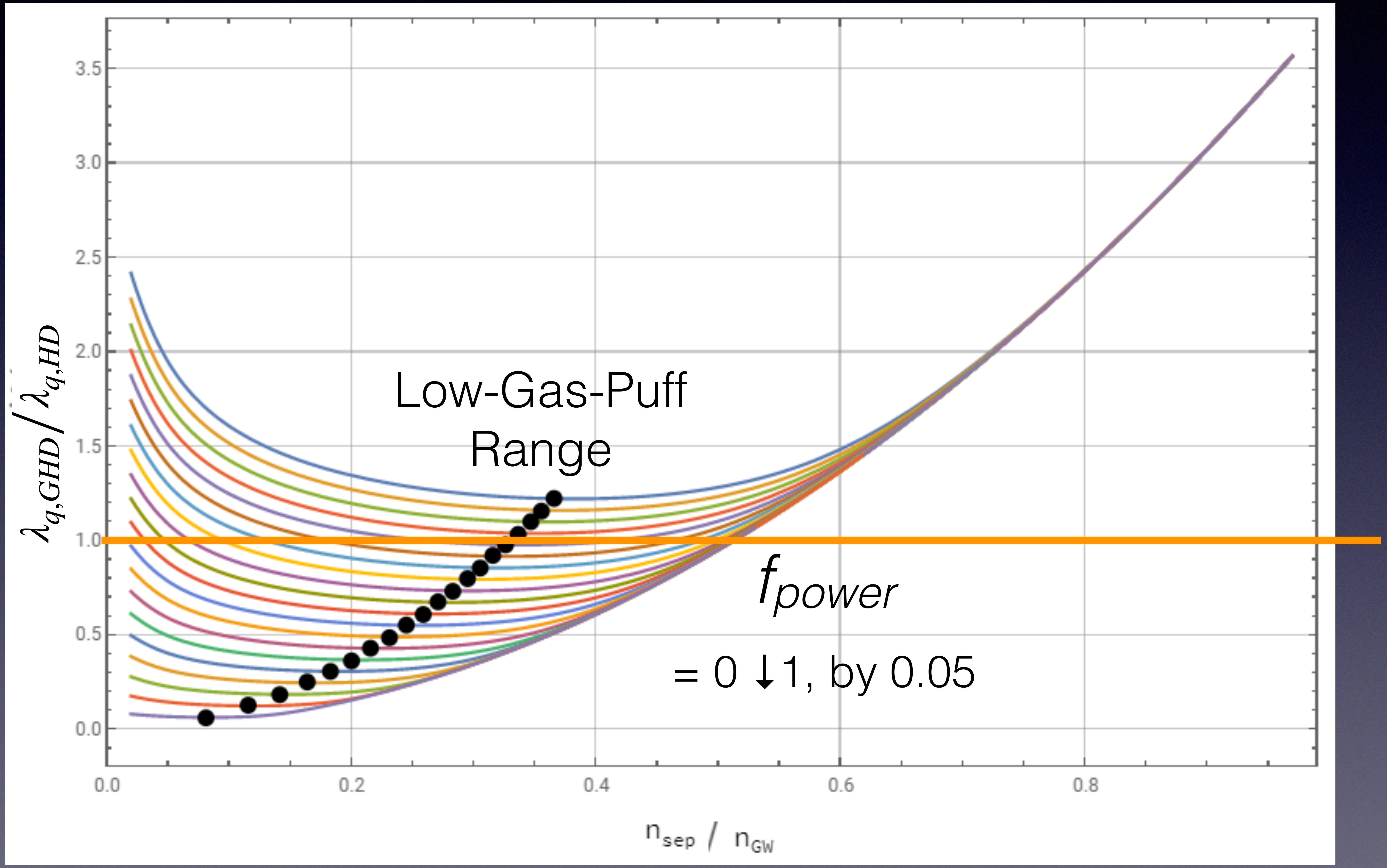
$$\tau_{E\|} = \frac{3 n_u T_u L_\|}{q_{\|,u}} \quad \text{and} \quad \lambda_{q,GHD} \sim \tau_{E\|} v_{d,u}$$

- Use the 2PM for heat diffusion along B and heat loss at the target:

$$T_{u,eV}^{7/2} - T_{t,eV}^{7/2} = \frac{7}{2} \frac{q_{\|,u} L_\|}{\kappa_0} \quad \text{and} \quad q_{\|,u} = \frac{\gamma n_t T_t c_{s,t}}{1 - f_{power}}$$

HD Model OK over Low-Gas-Puff Range

Sheath-limited: T_t affects T_u

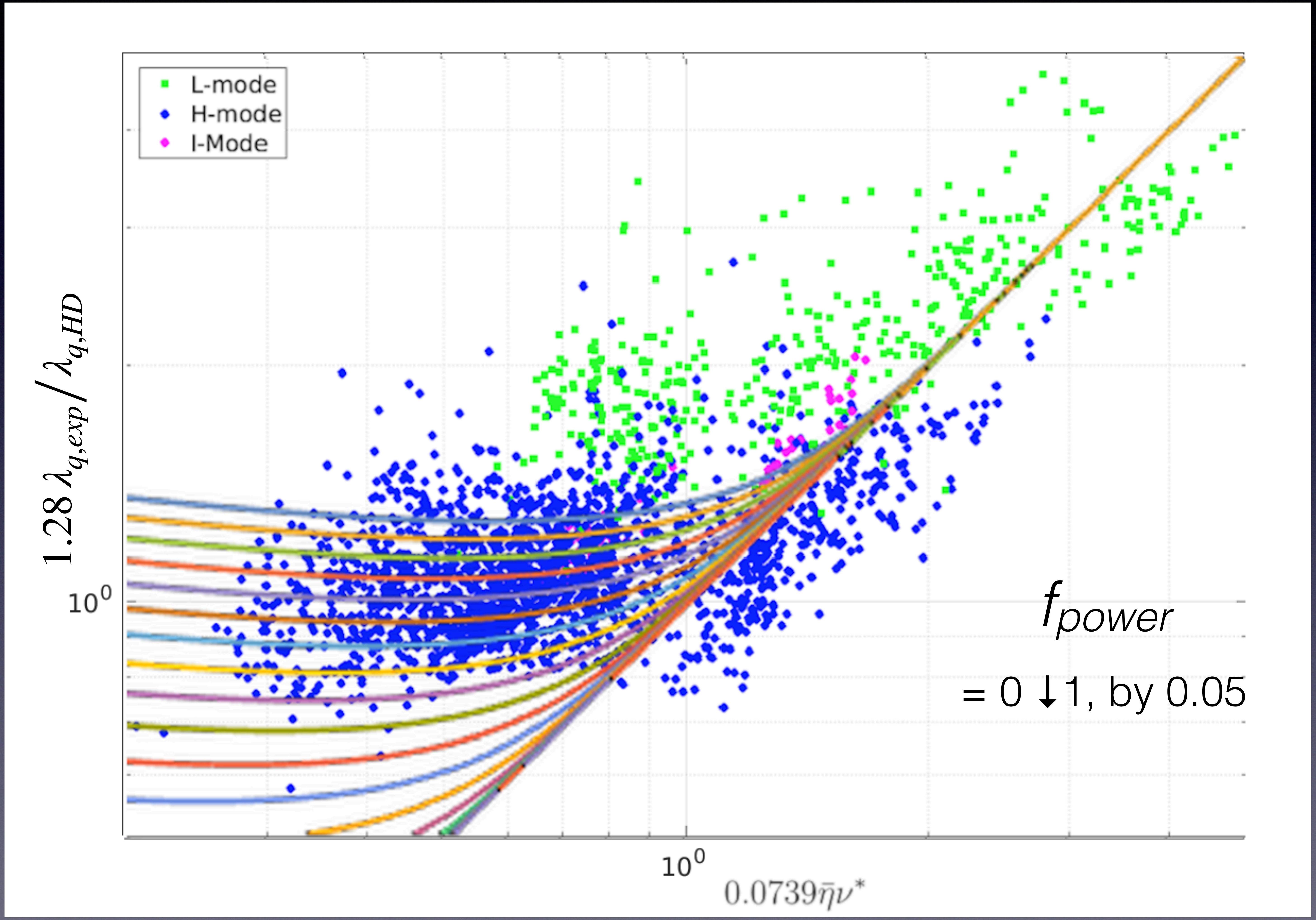


Collisional: Thermal resistance affects $\tau_{E,\|}$

HD Model

AUG-like parameters

Agreement with AUG H-Mode data OK



$$\bar{\eta}\nu^* \equiv \left(\frac{7/3}{1+2\lambda_T/(3\lambda_n)}\right)\left(\frac{1+Z}{A}\right)^{1/2}\left(0.672+0.076Z_{eff}^{1/2}+0.252Z_{eff}\right)\frac{10^{-16}n_{sep}L_\parallel}{T_{sep}^2}$$

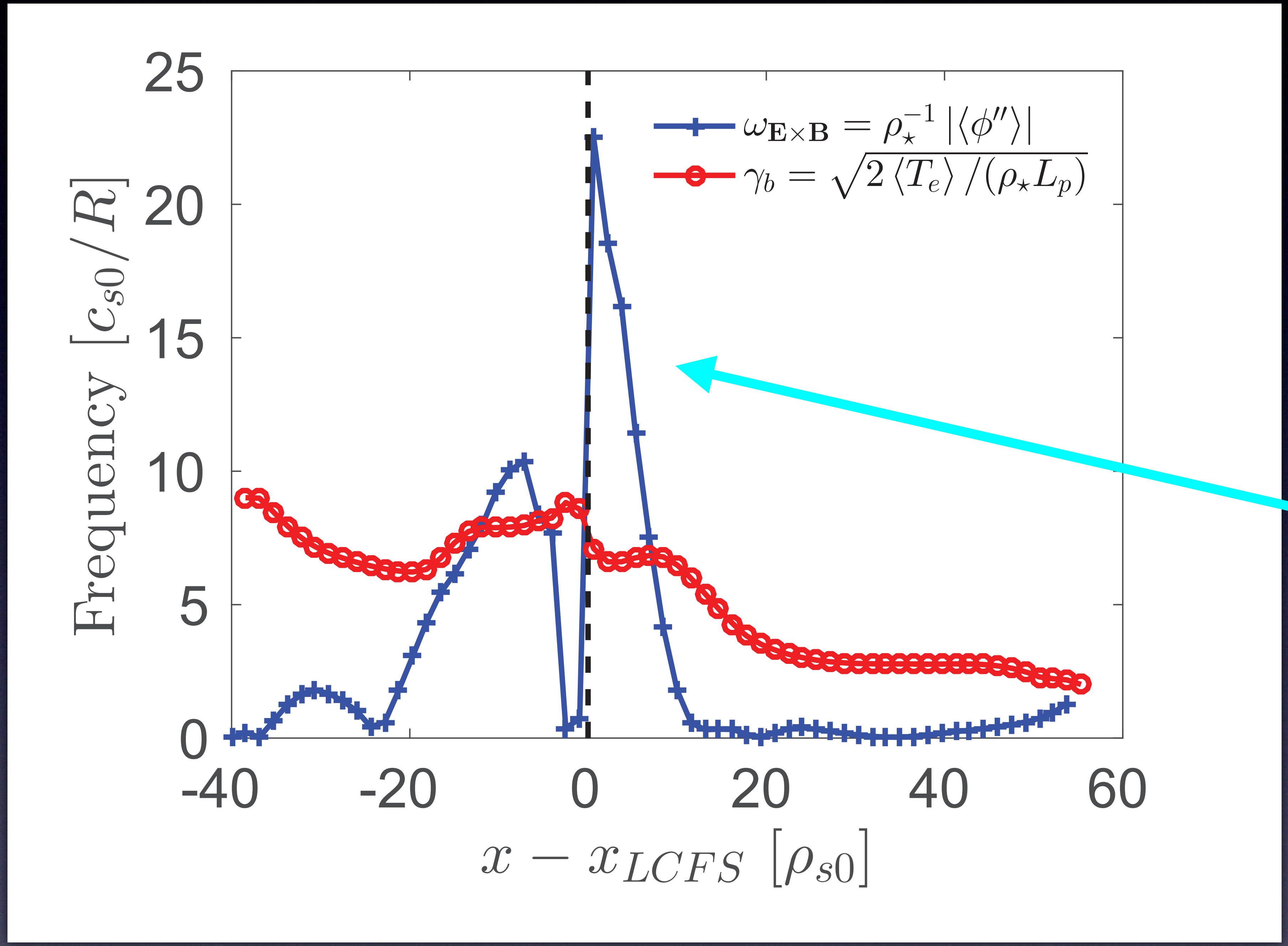
($q_\parallel$-weighted radially-averaged collisionality.)

Implications for Shear Flow Stabilization of SOL Interchange Turbulence

$$\omega_s \equiv |\phi''| \Big/ B_t$$

$$\gamma_{int} \equiv c_s \Big/ \sqrt{R\lambda_p}$$

GBS Simulations see Shear-Flow Effect



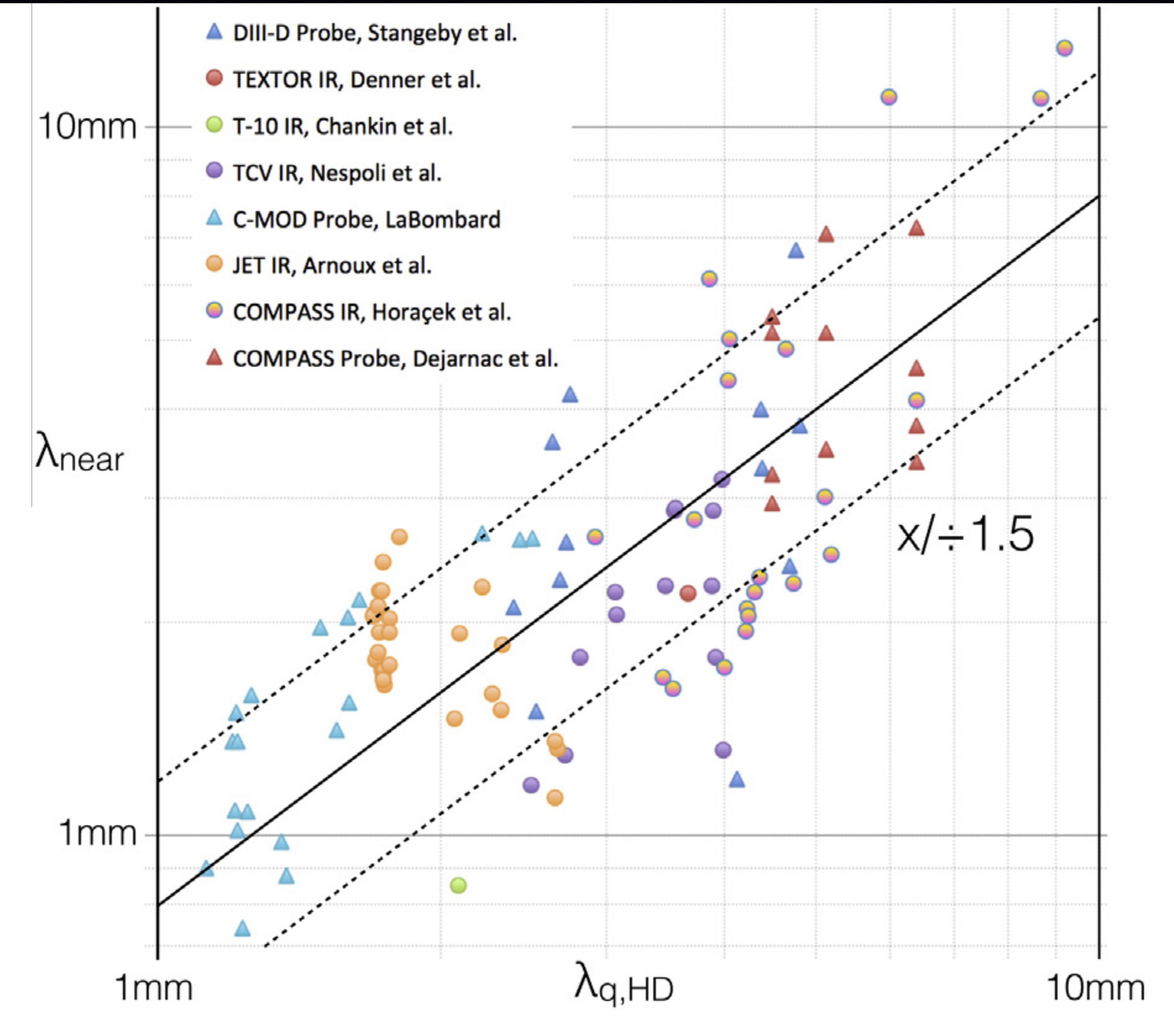
Halpern & Ricci (Nuclear Fusion, 2017)

$$\omega_s = |\phi''| / B_t$$
$$\gamma_{int} = c_s / \sqrt{R\lambda_p}$$

$\omega_s > \gamma_{int}$ in near-SOL region of inner-wall limited TCV plasmas, where λ_q ~ HD prediction.

We hypothesize here that the H-Mode in divertor plasmas requires $\omega_s \sim \gamma_{int}$ in the SOL.

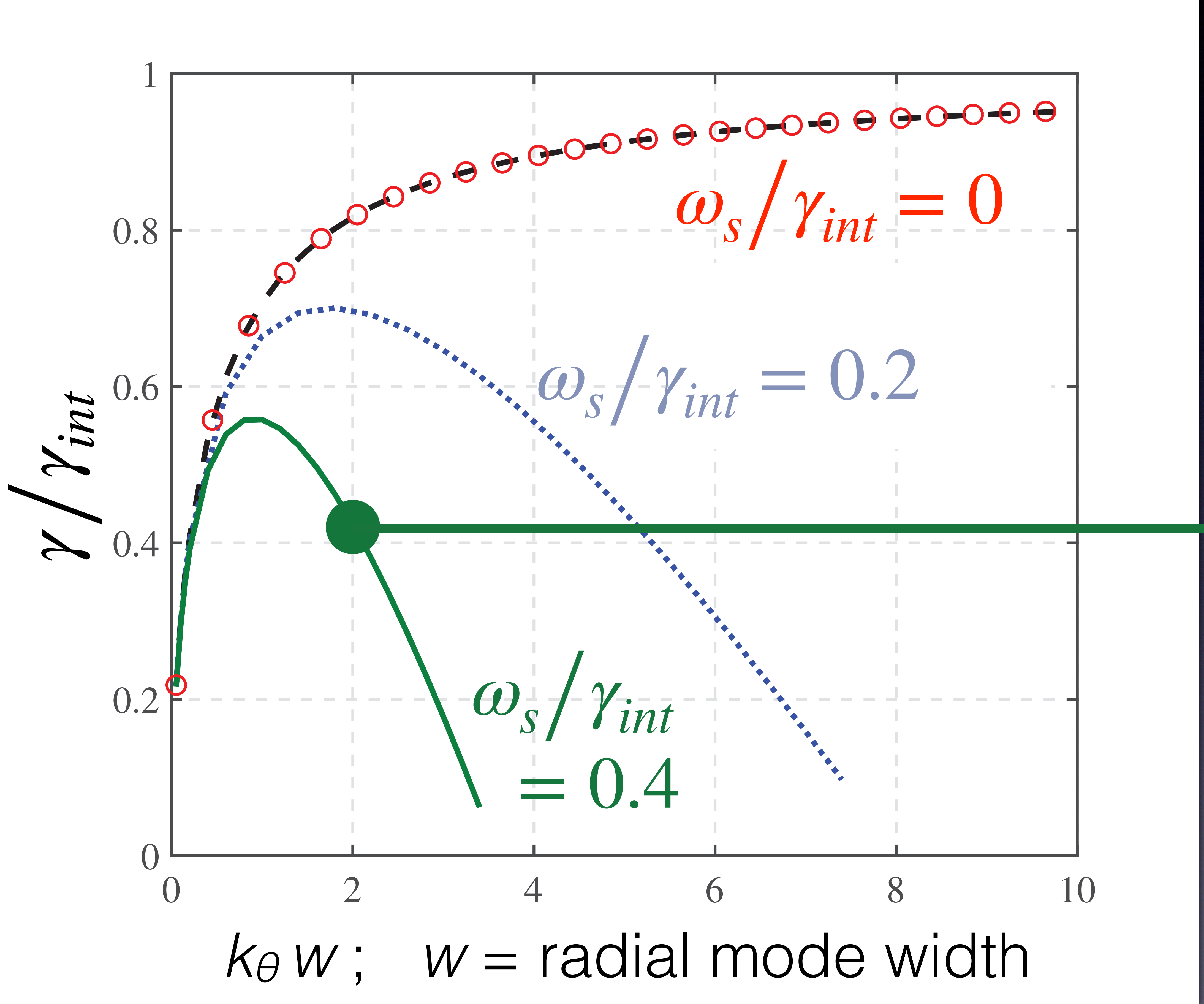
TCV Near-SOL Data ~ HD Prediction

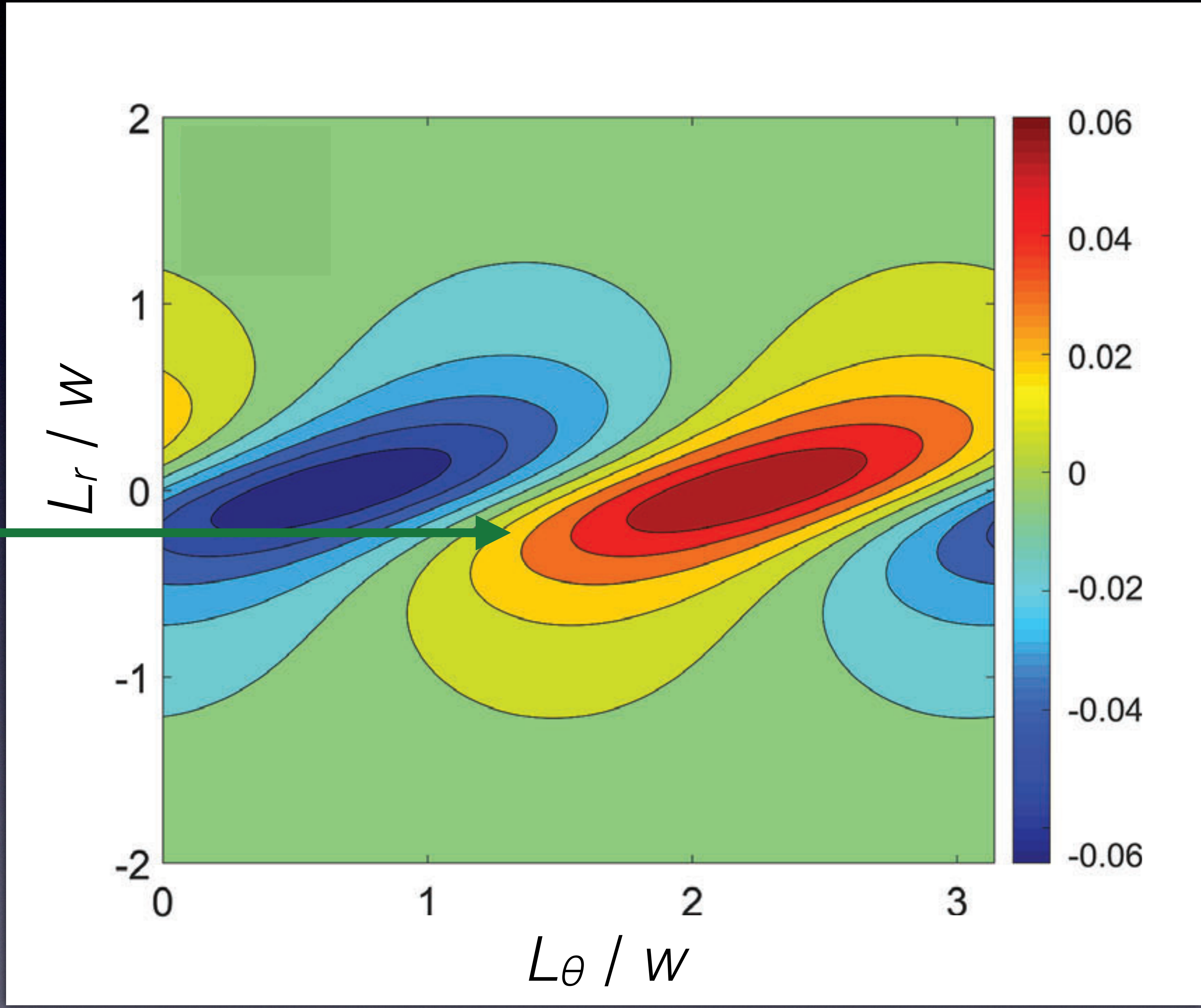


Goldston, JNME 2015

Near-SOL λ_q for inner-wall limited plasmas, vs. HD Model

Interchange Stabilization at High ω_s / γ_{int}

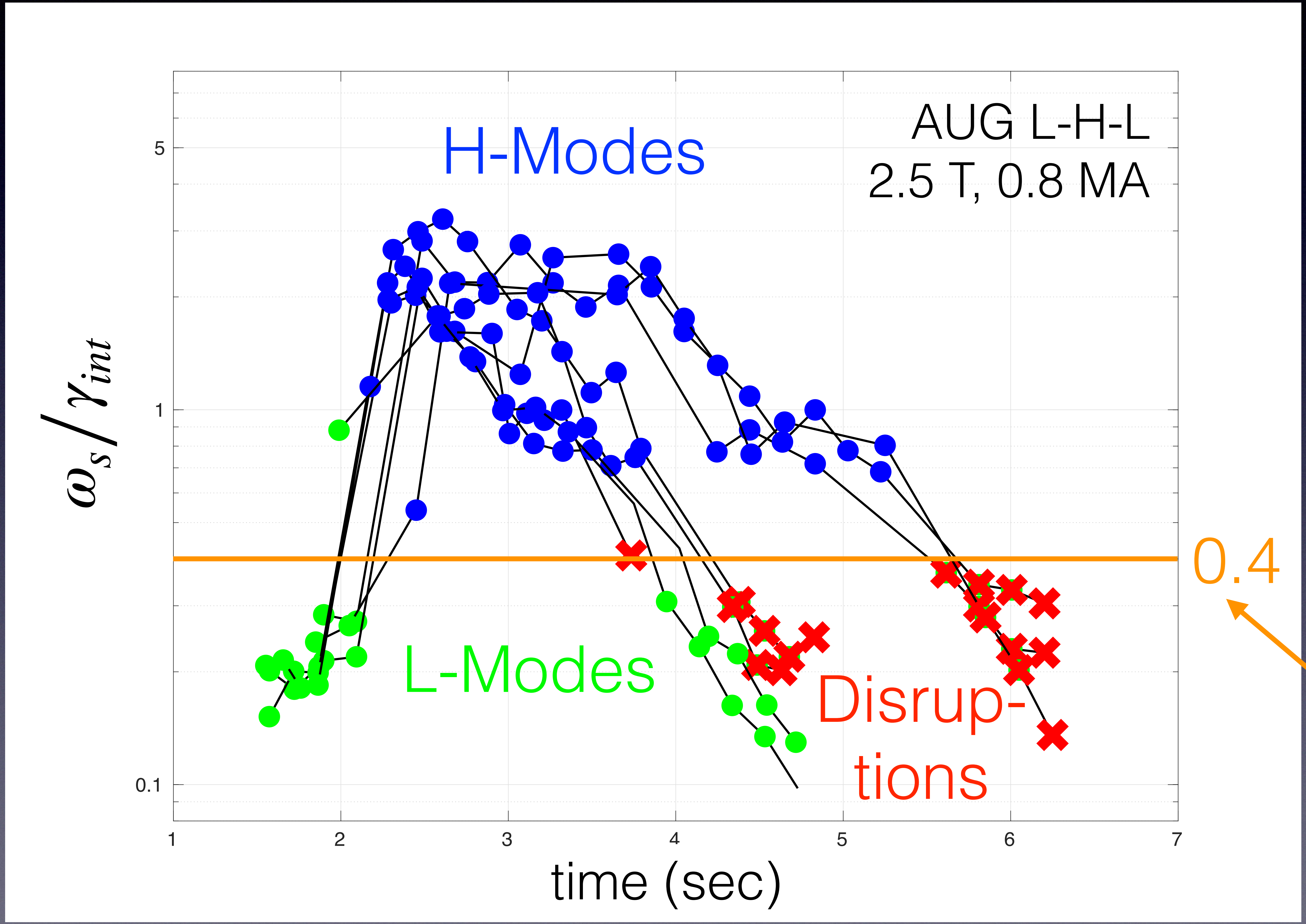




Zhang, Krasheninnikov, & Smolyakov (Contributions to Plasma Physics, 2019)

No interchange eigenmode for $\omega_s / \gamma_{int} > 0.4$.

AUG Data Support Role of ω_s / γ_{int}



2PM ansatz for upstream potential (Stangeby & Chankin NF 1996):

$$\omega_s = \frac{3T_t + \left(0.71 + \ln(2)/\ln(f_T)\right)(T_u - T_t)}{eB\lambda_{T_e}^2}$$

T_t and $f_T = T_u/T_t$ from the 2PM, using upstream TS data. Assumes $j_{\|} = 0$.

Poor for very low density?

γ_{int} from upstream TS data.

Zhang, Krasheninnikov, and Smolyakov, CPP 2019

Snap in, decays slowly with increasing density.

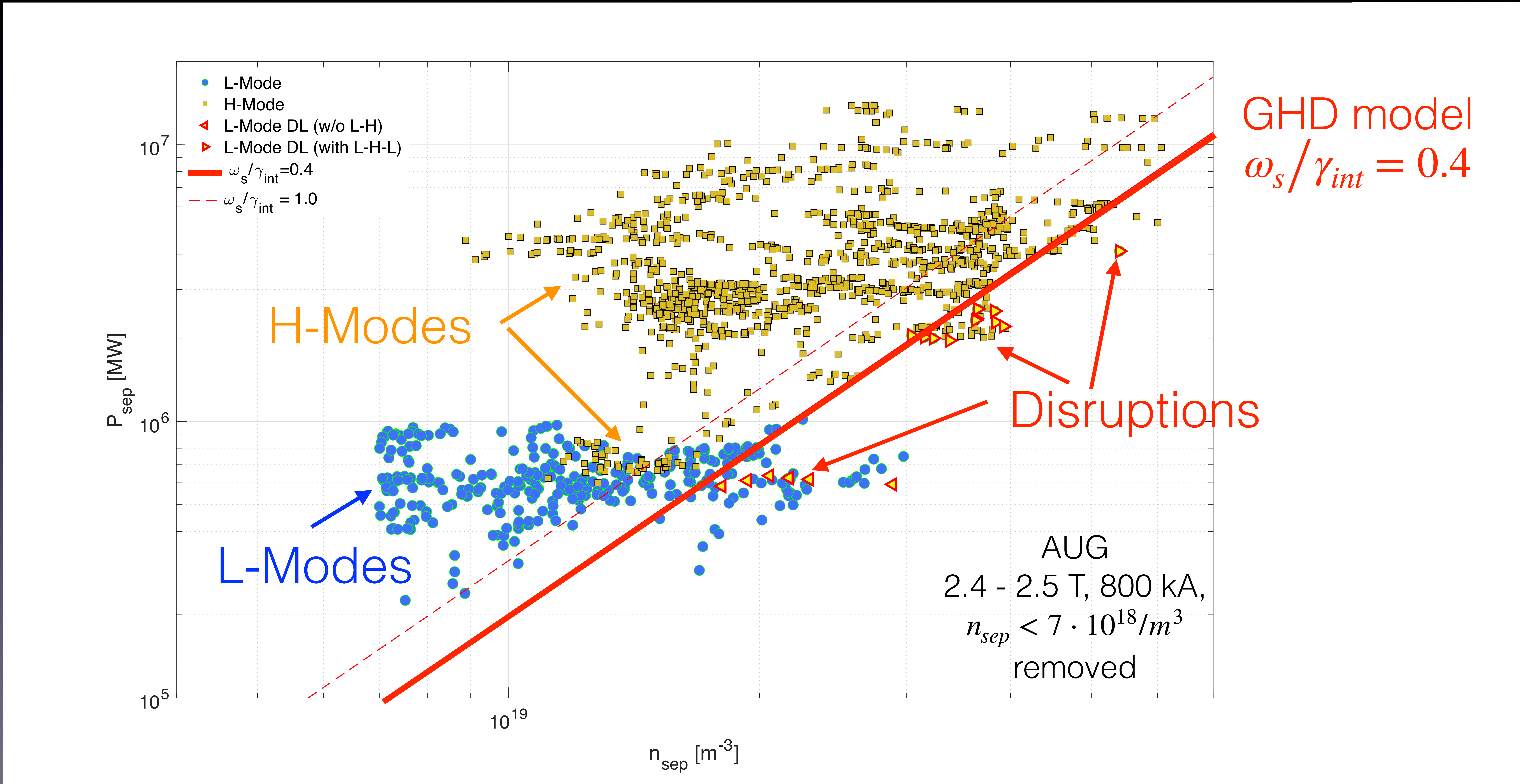
GHD H→L P_{sep} Scalings ~ AUG Data

$$P_{sep,H\to L} \propto n_{e,sep}^{\alpha} q_{cyl}^{\beta} B_t^{\gamma}$$

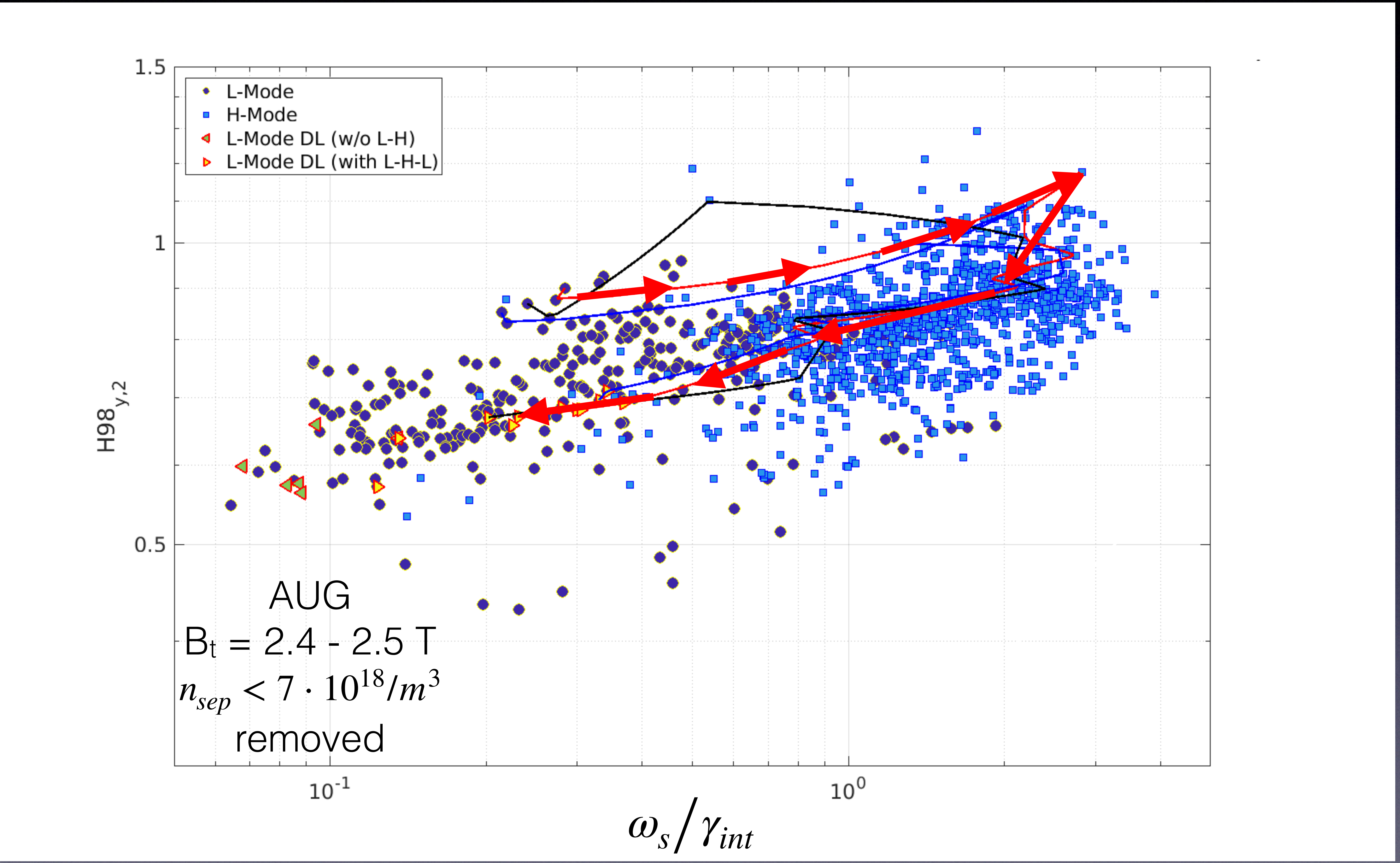
	GHD	Bernert
$n_{e,sep}$ (α)	2.07	2.53 (H5)
q_{cyl} (β)	2.24	1.48
B_t (γ)	-1.3	-0.67

- Bernert et al. (PPCF, 2015) only had “H5” density, line averaged over outer region of the plasma, not n_{sep}. *This is likely to skew the scalings.* (Bernert et al. expressed the threshold in terms of n_{H5} *vs.* q_{cyl}, P_{sep}, B_t.)
- **GHD captures general trends, including negative power scaling with B_t.**

Agreement OK for GHD H→L P_{sep} vs. n_{sep}



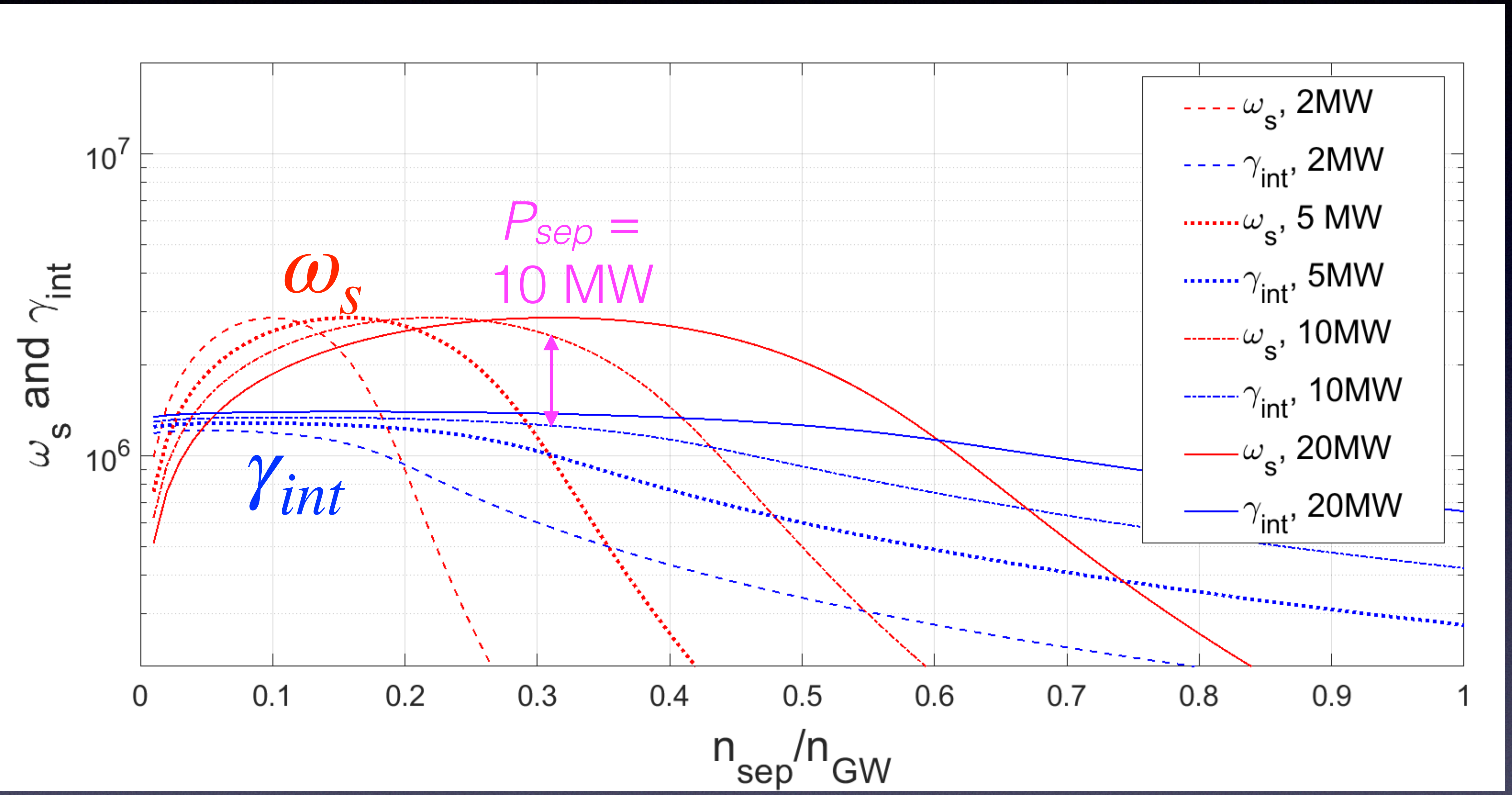
Confinement Improves for ω_s / γ_{int} up to ~2



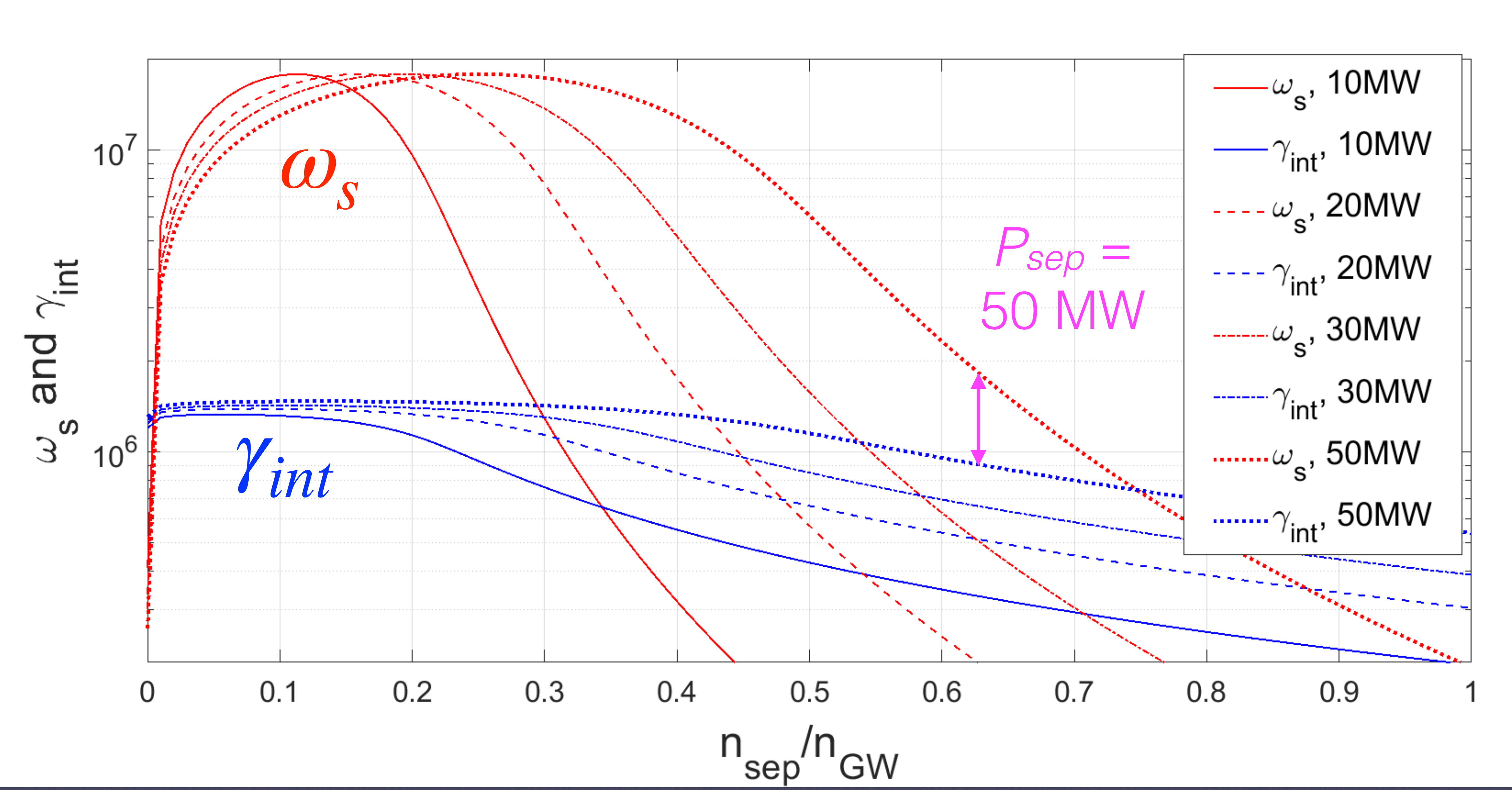
See also:
Silvagni et al. PPCF 2020.
Brunner et al. NF 2018.

Confinement degrades on the way down in ω_s / γ_{int} to the back-transition.

Favorable Prediction for ITER



AUG



ITER

ITER H-Modes predicted to have high $\omega_s / \gamma_{int} \approx 2$ at high n_{sep} / n_{GW} ~ 0.6.

Could the low-density end be related to higher H-L transition power there?
Possible role of parallel current in reducing upstream potential?

Conclusions

- HD Model can be generalized (GHD) to lower & higher collisionality.
- At high collisionality, GHD predicts λ_q to grow ~ like experiment.
- AUG data shows a strong correlation of ω_s / γ_{int} with H vs. L Mode.
  - Consistent with theory for interchange stabilization.
- GHD model predicts P_{sep} vs. n_{sep} for H→L transition ~ like AUG.
- ω_s / γ_{int} correlates with improved confinement.
- GHD model predicts high ω_s / γ_{int} at high n_{sep} / n_{GW} for ITER.
- More work to be done varying parameters in AUG and elsewhere.
  - Also direct (probe?) measurements of ω_s and γ_{int}.