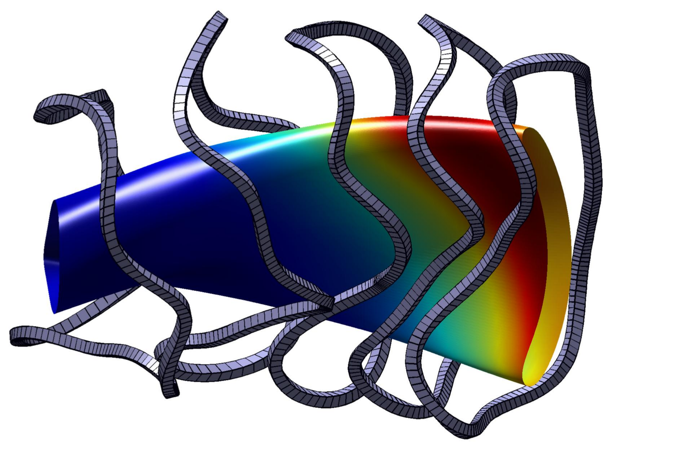
Expanding the CIEMAT-QI family of quasi-isodynamic stellarators

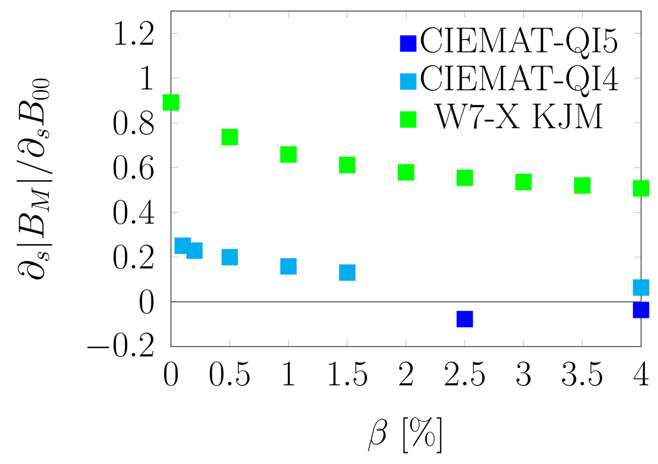
G. Godino-Sedano[1], J. L. Velasco[1], and E. Sánchez[1]

[1]Laboratorio Nacional de Fusión, CIEMAT, Madrid, Spain

Main Goals

Published earlier this year, the 4 period CIEMAT-QI4 [Sánchez, NF 2023] is a quasi-isodynamic stellarator configuration, which first displayed simultaneously the following set of properties.



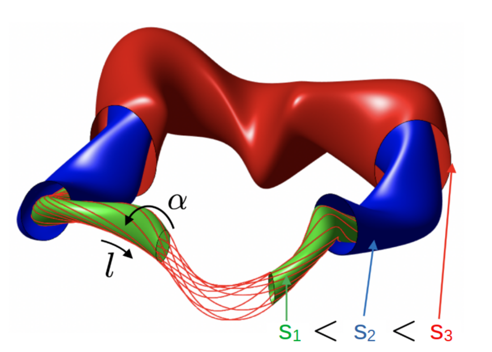


- Iota profile allowing for island divertor.
- Avoid low order rationals in the plasma.
- Ideal MHD stability.
- **Low neoclassical energy transport**.
- **Low fast ion losses**: Good at $\beta = 1.5\%$, excellent at $\beta = 4.0\%$.
- **Low bootstrap current**.
- **Reduced turbulence** (via maximum-J).
- Several sets of filamentary coils that preserve these qualities.

This work aims to explore a similar configuration space for other periodicities and to explore the effects of aspect ratio and maximum elongation κ_{Max}, to this end we have made some further choices:

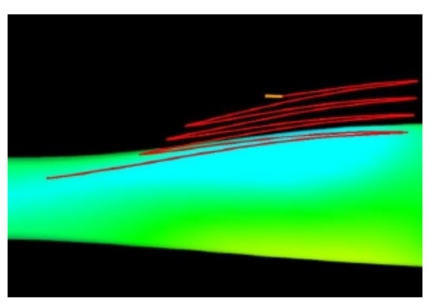
- 5 field periods (3 and 6 not in this poster),
- optimisation performed at $\beta \sim 2.5\%$.

Targets and variables of the optimisation

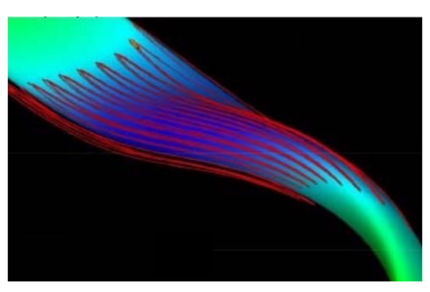


- $s = \psi/\psi_{LCFS}$: flux surface label,
- α: field line label,
- l: B-line arc length.

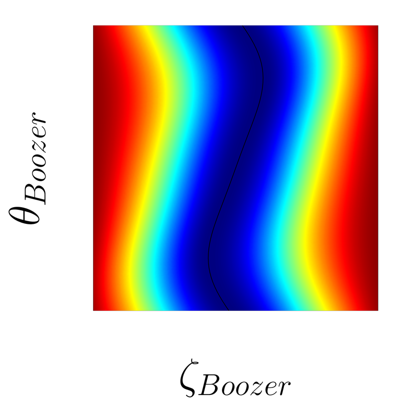
- Trapped particles (ions and e^-) quickly bounce back and forth along field lines (due to μ conservation, magnetic mirrors).
- There is a slower drift between the field lines, which is at constant $J = \int_{l_1}^{l_2} m v_{||}\,\mathrm{d}l$.
- Radial drift that does not average to 0 can lead to radial transport and losses.
- Poloidal drift can compensate the former with a wider exploration of the flux surface.



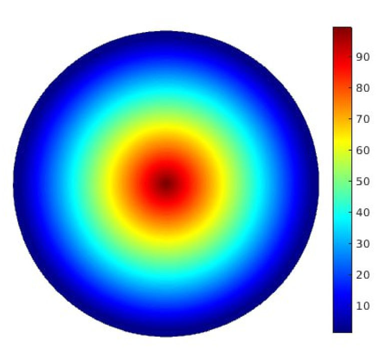
$$\overline{v_d \cdot \nabla s} \propto \partial_\alpha J$$
$$\overline{v_d \cdot \nabla \alpha} \propto -\partial_s J$$



Omnigeneity	Quasi-isodynamicity	Maximum-J
$J = \int_{l_1}^{l_2} m v_{\parallel}\,\mathrm{d}l$ $\overline{v_d \cdot \nabla s} \propto \partial_\alpha J = 0$	Omnigeneous with poloidally closed |B| contours.	$-\overline{v_d \cdot \nabla \alpha} \propto \partial_s J < 0$, $\left\lvert\frac{\overline{v_d \cdot \nabla s}}{\overline{v_d \cdot \nabla \alpha}}\right\rvert \propto \left\lvert\frac{\partial_\alpha J}{\partial_s J}\right\rvert = 0$
- Low neoclassical transport - Low FI losses	- Low bootstrap current allows island divertor	- Reduced turbulence - Low FI losses
Effective ripple ϵ_{eff}	Variance of |B| on poloidal contour of minima Variance of |B| on poloidal contour of maxima No explicit bootstrap target yet	Γ_C [Nemov PoP 2008] Γ_α [Velasco NF 2021]



Sketch of exact QI field



Sketch of exact max-J

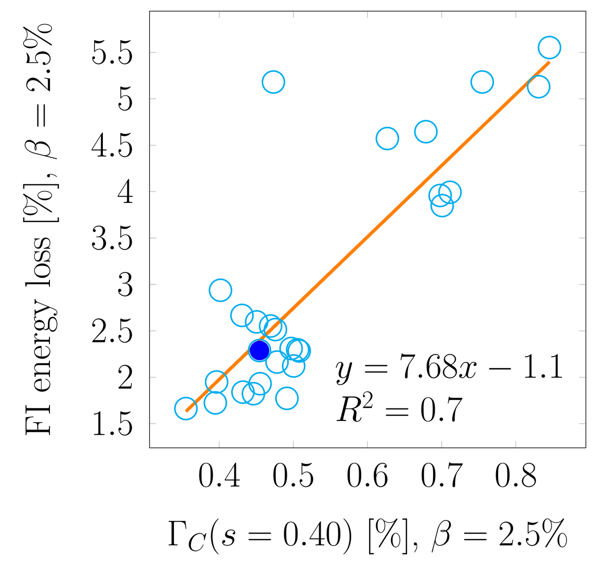
Conclusions

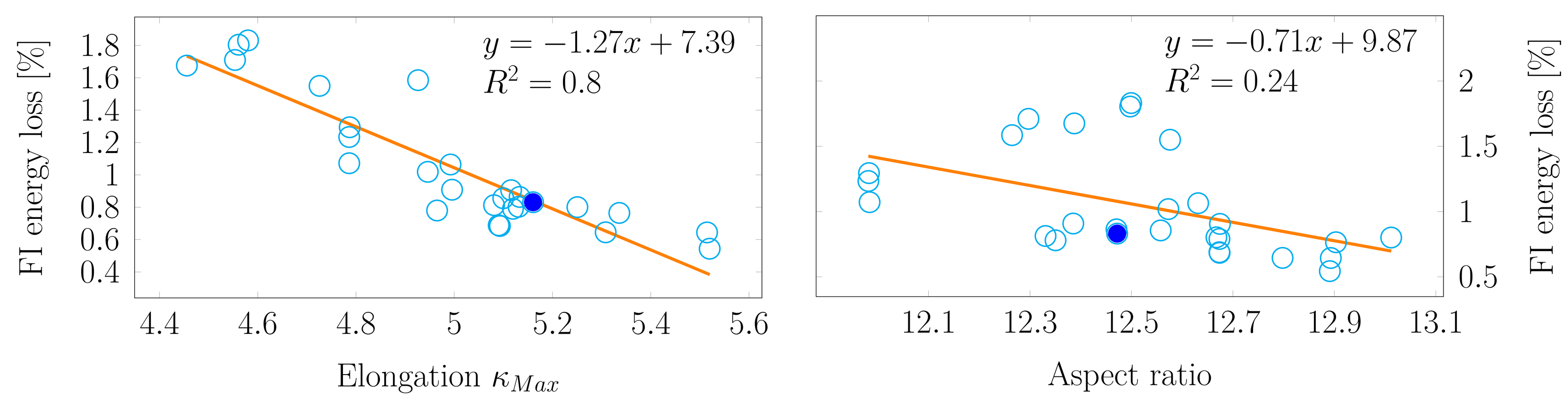
- Work on its way to replicate CIEMAT-QI4 for 5 other periodicities.
- Initial study into Pareto-efficiency and relations between quantities of interest.
- Neoclassical properties improved over CIEMAT-QI4.
- Next steps: coil design and improvements on 3 and 6 period configurations.

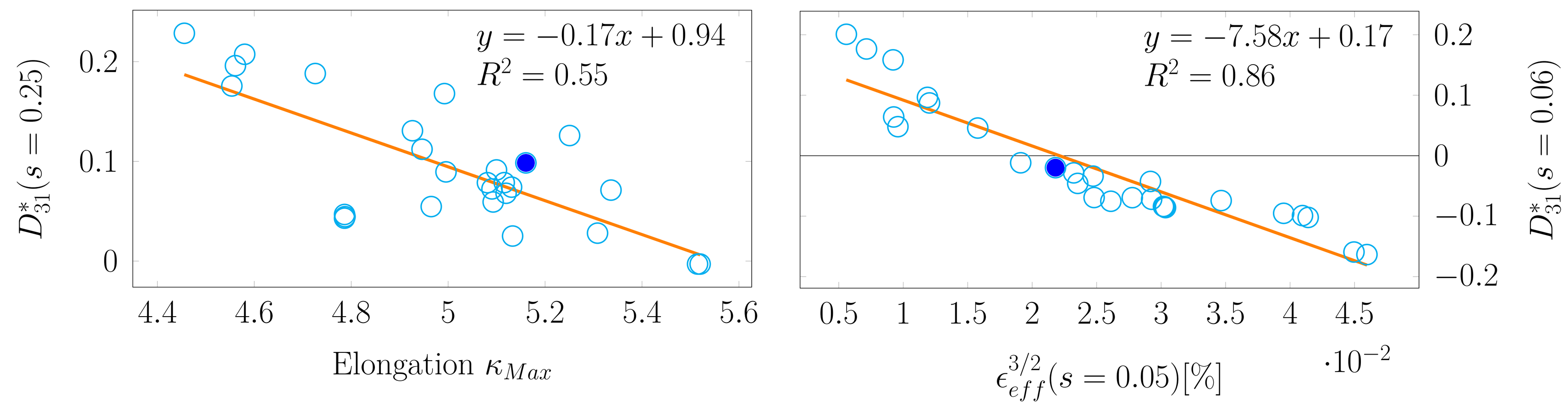
Exploring the configuration space

We are considering all 5 period configurations that are MHD stable and satisfy the iota requirements, and choose to compare:

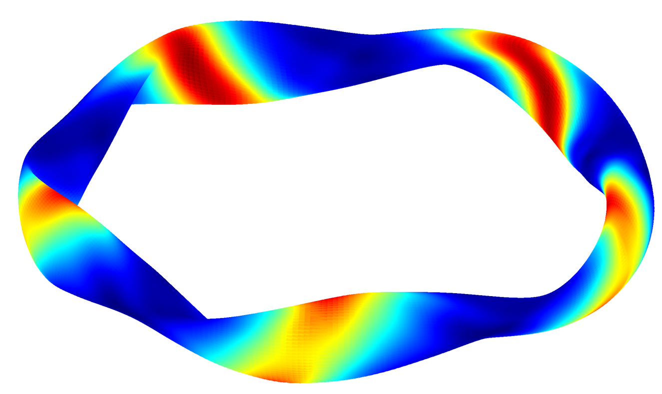
- aspect ratio,
- elongation κ_{Max},
- plasma beta β,
- Γ_C at and beyond half-radius,
- ϵ_{eff} up to half-radius.

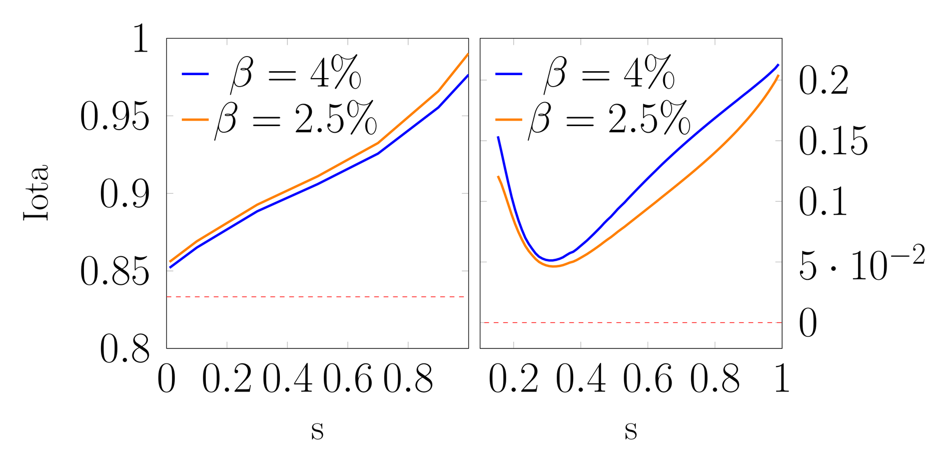




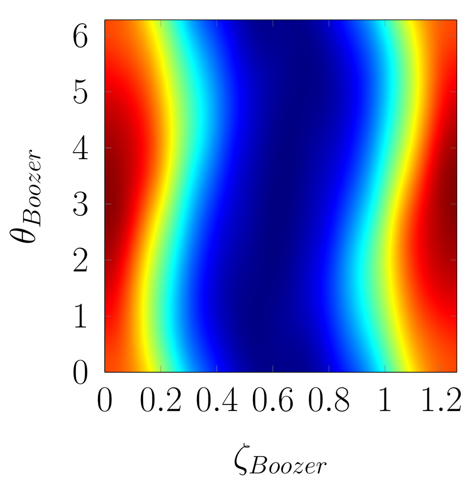


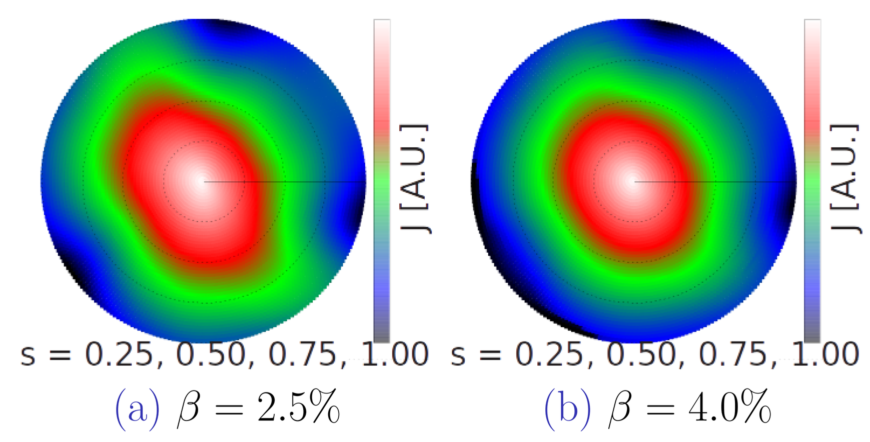
Selected 5 period configuration

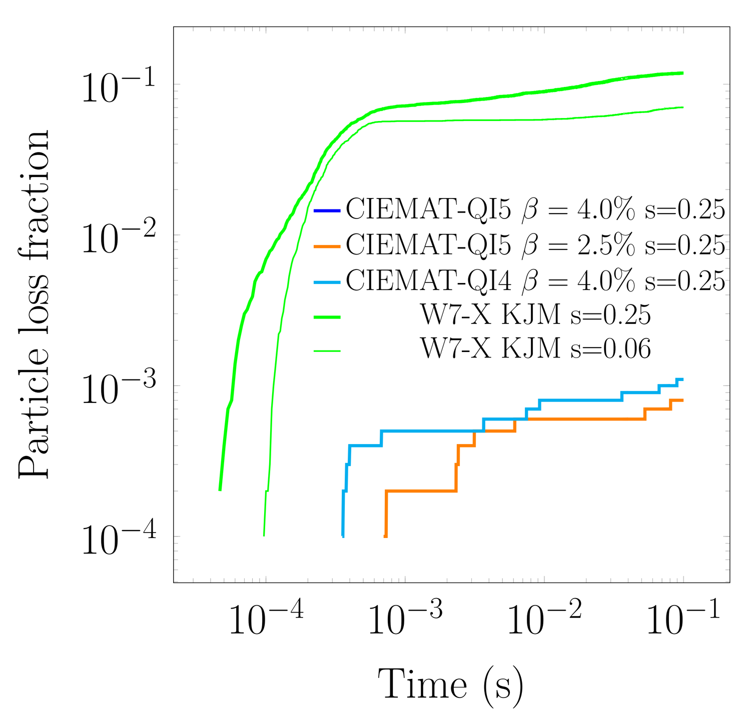


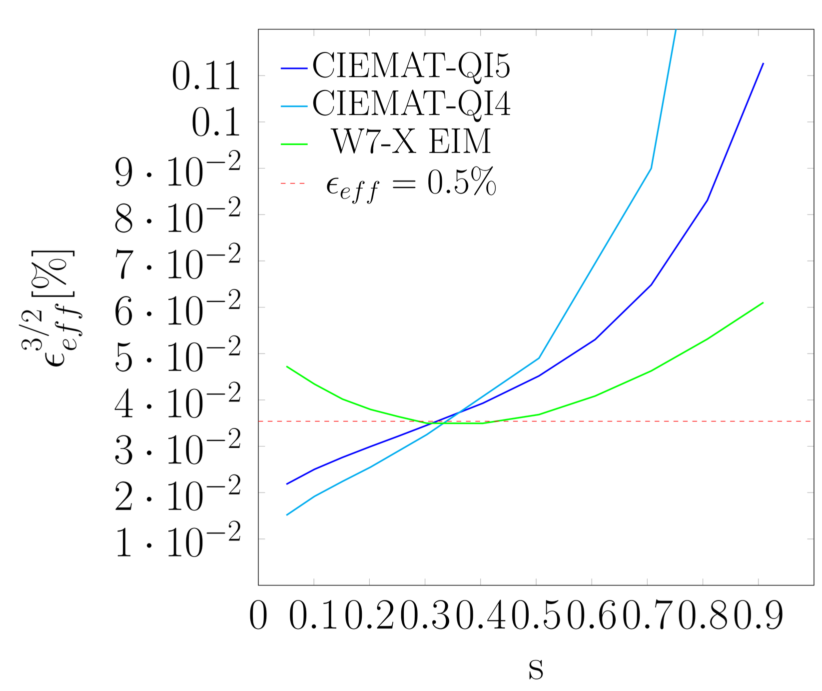


For $s > 0.1$, this configuration is Mercier-stable at $\beta > 1.0\%$.
For all s, it is ballooning stable at $\theta = 0$, $\zeta = 0$.

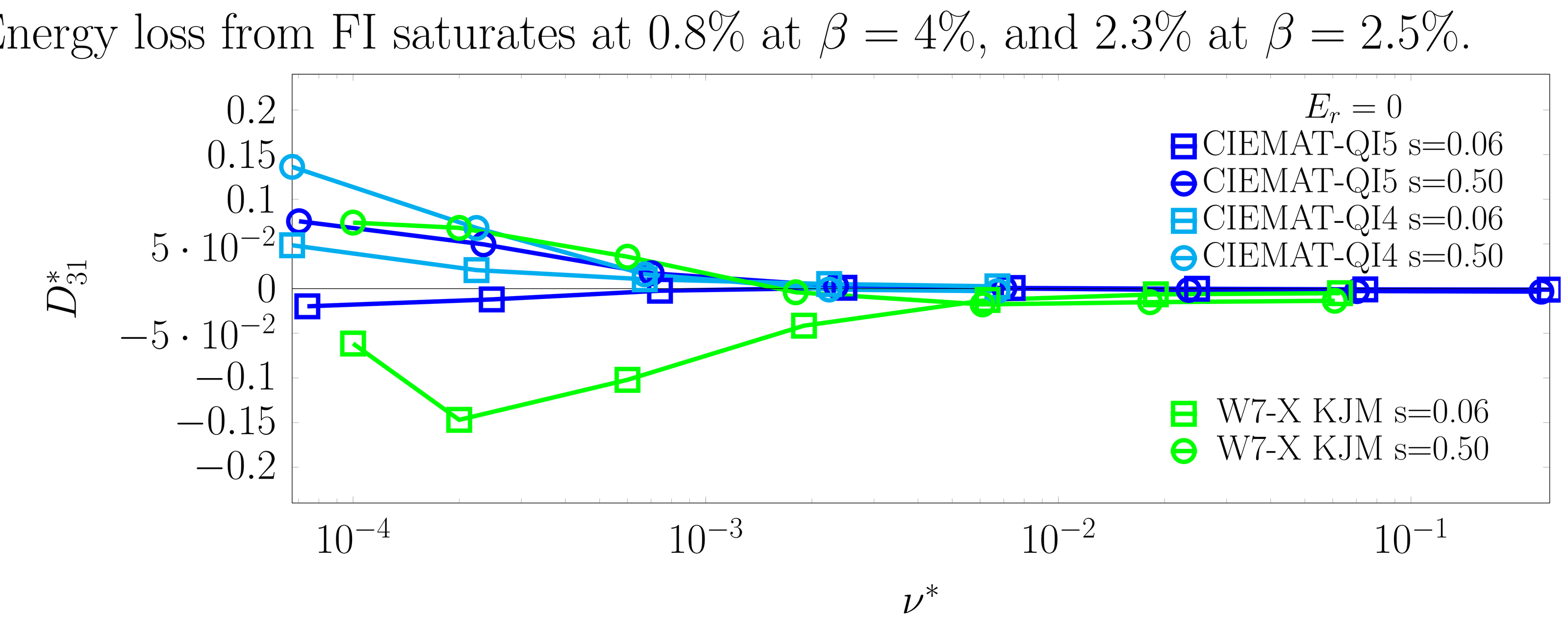








Energy loss from FI saturates at 0.8% at $\beta = 4\%$, and 2.3% at $\beta = 2.5\%$.



GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
UE 23
Laboratorio Nacional de Fusión Ciemat
EUROfusion
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.