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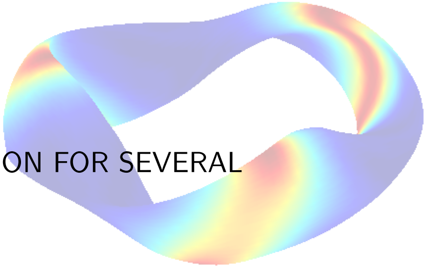

QUASI-ISODYNAMIC STELLARATOR OPTIMISATION FOR SEVERAL PERIODICITIES WITH A GENETIC ALGORITHM

3rd Fusion HPC Workshop

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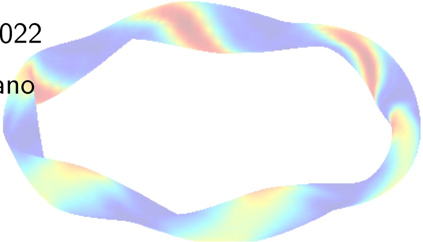

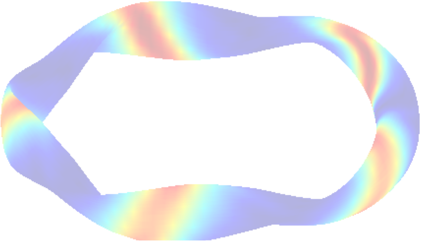

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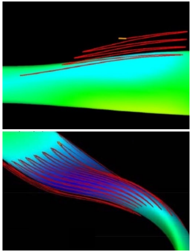
WHY OPTIMISE STELLARATORS?

NEOCLASSICAL TRANSPORT AND FAST IONS

- Stellarators require improvements in some aspects to compare to tokamaks.
- One such aspect is the confinement losses due to neoclassical transport.
- Collisionless trapped particle orbits are inherently confined in axissymmetric tokamaks, not so in generic 3D fields.



Credit: R. Kleiber

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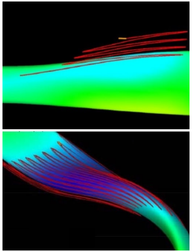

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Fast ions (3.5 MeV fusion alphas in a reactor)

- Alphas' energy should be deposited in the bulk.
- Energetic alphas escaping may damage plasma-facing components.

Bulk (thermal) ions

- Major contribution to energy transport at low collisionality.

Stellarators' many degrees of freedom enable detailed optimisation.

OMNIGENEITY AND QUASI-ISODYNAMICITY

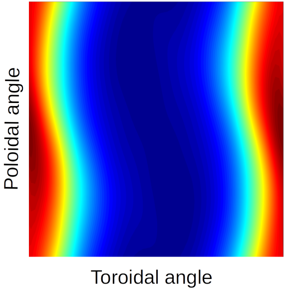
Omnigeneity: orbit averaged radial magnetic drift, $\overline{v_M \cdot \nabla r} = 0$.

A quasi-isodynamic (QI) field:

- omnigenous,
- poloidally closed B-contours.

Benefits of QI fields:

+ no collisionless fast ion losses,
+ low neoclassical transport of bulk ions,
+ zero bootstrap current,
+ low TEM turbulence in some cases.



OBJECTIVES TO OPTIMISE IN STELLARATORS

Objectives

Island divertor configuration
Good vacuum flux-surfaces

MHD stability

Low fast ion losses
Low bulk neoclassical transport
Low bootstrap current

Reduced turbulent transport

Feasible coil configuration

Constraints used

Reactor-relevant plasma $\beta \sim 4\%$
Adequate aspect ratio $A \sim 10$
Period numbers: 3, 5 & 6.

4 period LNF QI has already been optimised.
[Sánchez, ISHW 2022 (paper submitted to NF: arXiv: 2212.01143)]

STELLARATOR OPTIMISATION WITH A GENETIC ALGORITHM

PARAMETERS, OBJECTIVES AND TARGETS

Parameters

- Quantities that are varied independently
- Values restricted to a domain

- for example: LCFS shape.

Objectives

- Equilibrium quantities of interest
- They should approach a set of ideal values: targets

- for example: fast ion losses.

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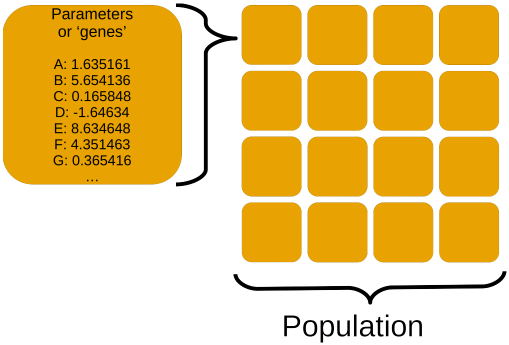
Multi-objective optimisation turns into single-objective optimisation of a cost function:

$$\chi^2 = \sum_i \frac{(f_i^{objective} - f_i^{target})^2}{\sigma_i^2}$$

The optimisation code suite STELLOPT minimises χ^2 for a given set of targets $\{f_i^{target}\}$ and their corresponding weights $\{\sigma_i\}$.

[S. A. Lazerson et al. (www.osti.gov/biblio/1617636)]

GENETIC ALGORITHM WITH DIFFERENTIAL EVOLUTION



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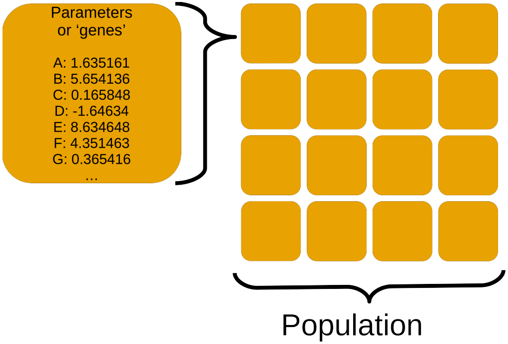
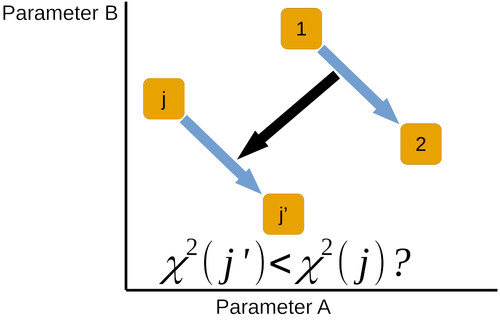




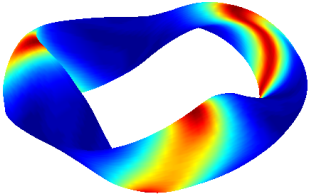
$$\chi^2 = \sum_i \frac{(f_i^{objective} - f_i^{target})^2}{\sigma_i^2}$$

PARAMETERS IN A STELLARATOR

Quantities that are allowed to vary independently, with values restricted to a domain. Usually restricted to ~ 60 dimensions.

A stellarator may be uniquely determined by:

1. last closed flux-surface shape: RBC & ZBS fourier coefficients,
2. pressure profile,
3. toroidal current profile (invariant, set to 0).



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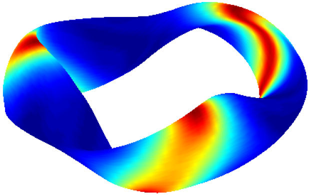

Using these inputs, VMEC calculates the equilibrium for each stellarator design in every iteration of the optimiser.

Other codes then calculate the equilibrium quantities of interest (next slide) to be optimised, requiring parallelisation to simultaneously compute the objectives' values.

Usually using 108 or 120 processors for $6 - 10$ hours at a time in CIEMAT's Xula server.

OBJECTIVES AND TARGETS USED

Objective name	Objective purpose	Target value
Aspect ratio		~ 10
β		$\sim 4\%$

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	Island divertor	$\iota_{s=1} \lesssim 1$
Magnetic well	MHD stability	$W > 0$
Radial derivative of B_{00}	Omnigeneity	$\partial_s B_{00} > 0$

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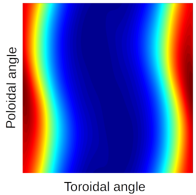
Variance of B at minima	QI	0
Variance of B at ζ=0	QI	0
Variance of B at maxima	QI	0
Width of B well	QI	0



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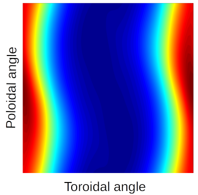
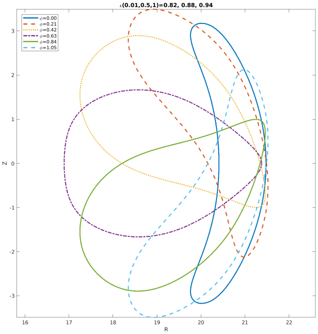


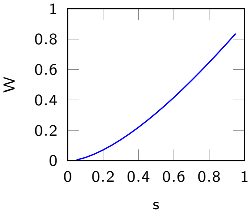
Turbulence and bootstrap are *not* explicitly included in the optimisation.

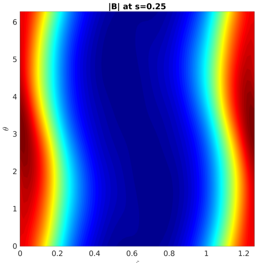
RESULTS

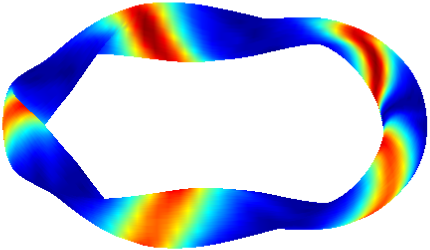
5 PERIODS: β=4.2%, A=11.5

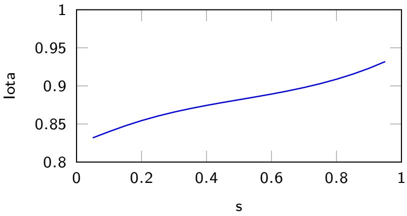
ARIES-CS scale:
B=5.7T, a=1.7m





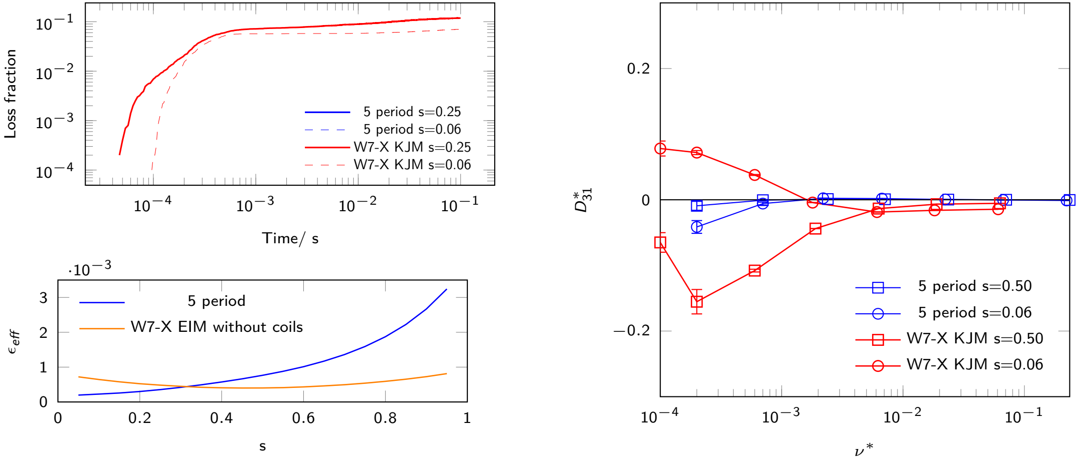






5 PERIODS: β=4.2%, A=11.5

By t=0.1 s, there are no losses of fast ions born at s=0.06 nor s=0.25.



6 PERIODS: β=4.4%, A=13.5

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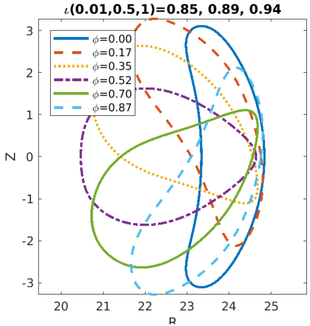

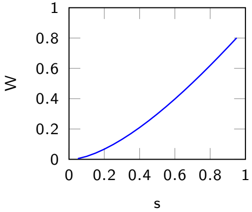

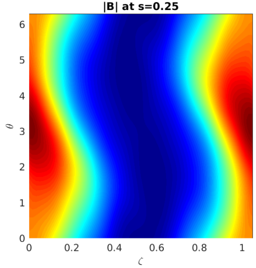

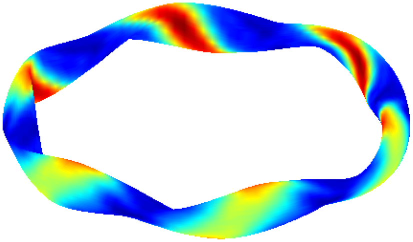

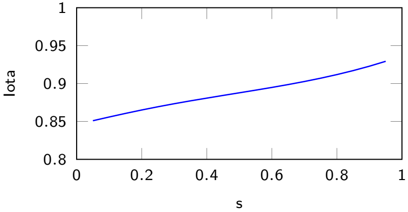

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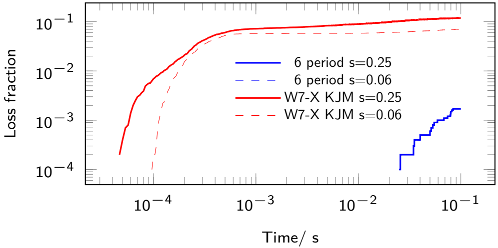

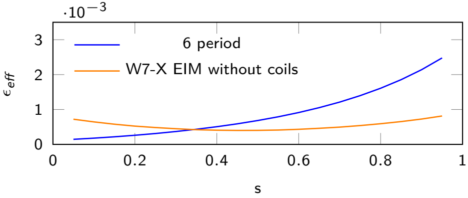

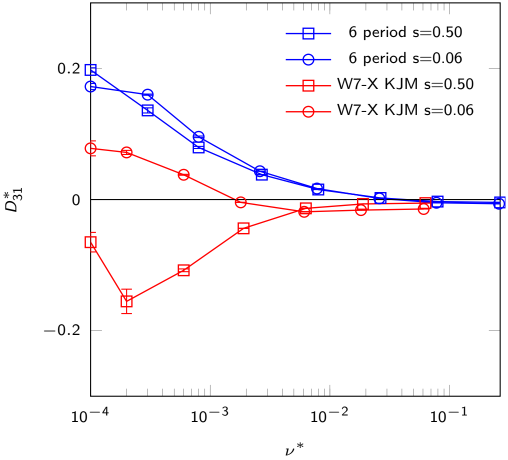

CONCLUSION

+ Both designs have a QI-like magnetic configuration and MHD stability.
+ Both are well optimised for bulk neoclassical transport and fast ions.
+ 5 period result improves on W7-X for fast ion losses, bulk transport at the core and bootstrap current.
+ 5 period result is comparable to the 4 period LNF QI design. [Sánchez, ISHW 2022 (paper submitted to NF: arXiv: 2212.01143)]
- Optimisation in 3 periods (not shown) less successful despite more computational resources.

> TEM turbulence is expected to be acceptably small due to closeness to QI at finite β (maximum-J property).

> Next step: coil design.

Thank you for your attention.