Impact of divertor protection against intolerable heat loads and tungsten sputtering on plasma performances using the SYCOMORE system code

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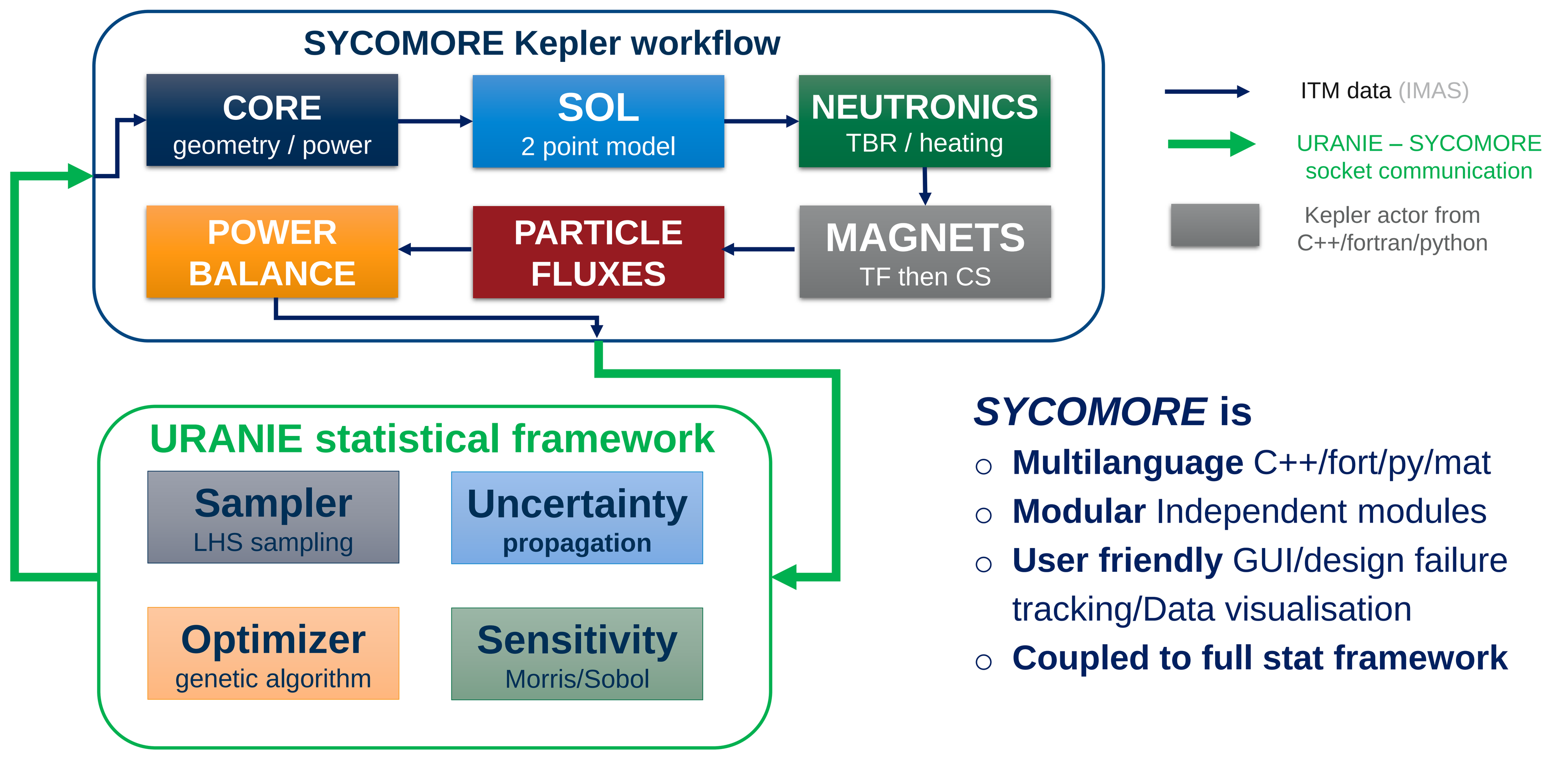
Abstract

The next step after ITER is the demonstration of stable electricity production with a fusion reactor. Key design performances will have to be met by the corresponding power plant demonstrator (DEMO), fulfilling a large number of constraints. System codes such as SYCOMORE, developed by CEA/IRFM using the EU-ITM platform [1-2], address those questions by simulating all the fusion power plant sub-systems. SYCOMORE uses an extended [3] two point model to simulate the scrape-off layer (SOL) physics, taking momentum losses and impurity radiation into account. As impurity radiation affects both the core and the SOL power balance, a coupling between the SOL and the Core models is designed to find the minimal impurity fractions necessary to protect the divertor targets from both intolerable heat flux per unit of surface (q_{peak}) and tungsten sputtering (maximum target plasma temperature T_{targ}). This coupling allows to address the effect of divertor protection on global power plant design key figures of merits such as the net electricity production (P_{net}) or the possibility to get the H-mode [7]. This analysis will present the update of the SOL impurity radiation model in SYCOMORE, and study the effect of the choice of the impurity seeding (Argon or Xenon) on global design performances. The effect of two key SOL parameters : the upstream power decay length (λ_q) and the separatrix density value is evaluated assuming several impurity transport properties. Although the SOL seeding impurity transport (τ_{Imp}) has only a marginal effect on the global design, the nature of the impurity specie and its propagation from the SOL to the core is shown to have a significant impact on the power plant performances.

The SYCOMORE system code

Aim : Complete power plant design optimization and robustness assessment (uncertainty/sensitivity)



***SYCOMORE* is**

- **Multilanguage** C++/fort/py/mat
- **Modular** Independent modules
- **User friendly** GUI/design failure tracking/Data visualisation
- **Coupled to full stat framework**

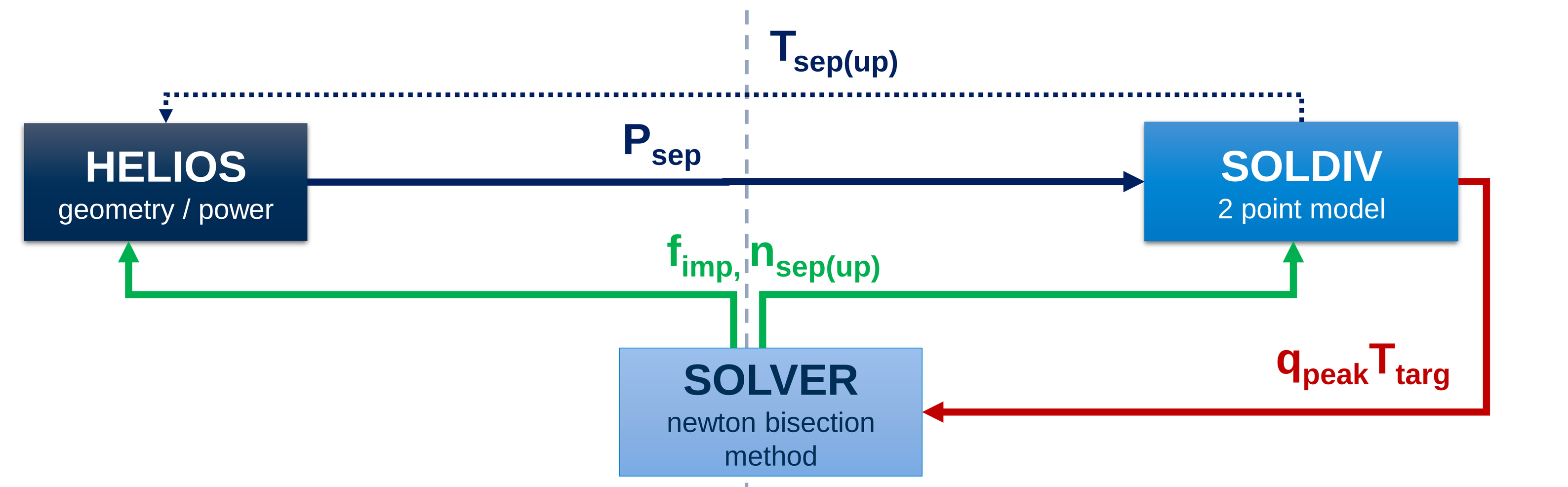
CORE / SOL coupling

CORE driven by [8]

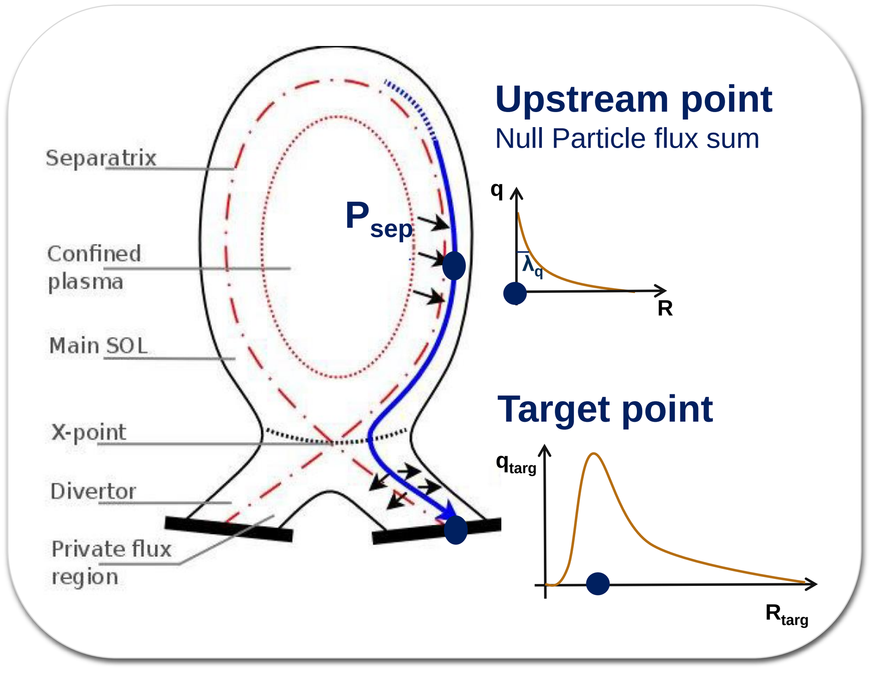
- Impurity fraction (f_{imp})
  → DT reaction dilution
  → Global line radiation
- Separatrix density ($n_{sep(up)}$)
  → Pedestal line radiation

SOL driven by [2]

- Impurity fraction (f_{imp}) and $n_{sep(up)}$
  → Divertor heat capacity (q_{peak})
  → Tungsten sputtering (T_{target})



The SOLDIV module



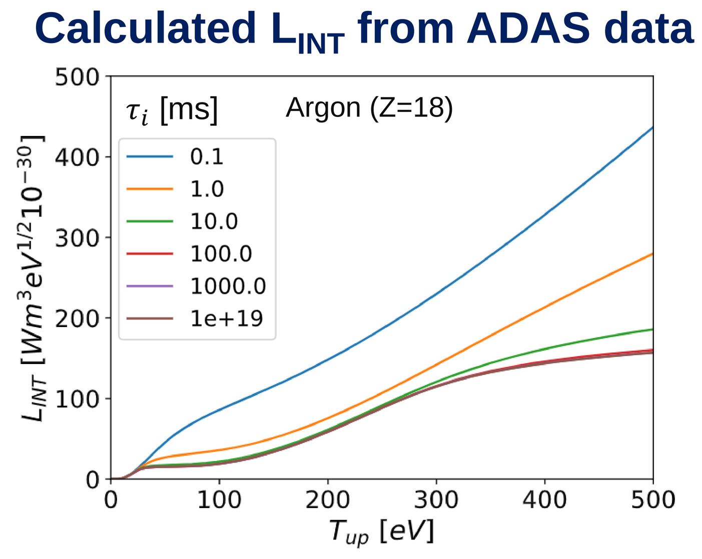
Extended 2 points model [3]

$$\begin{cases} n_u T_u \boxed{f_{mom}} = 2 n_t T_t \\ T_u^{\frac{7}{2}} = T_t^{\frac{7}{2}} + \frac{7 f_{cond} q_\parallel L}{2\kappa_{0_e}} \\ \left(1 - \boxed{f_{power}}\right) q_\parallel = \left(1 + \frac{\varepsilon}{\gamma T_t}\right) \gamma \Gamma_t T_t \end{cases}$$

Target momentum losses (f_{mom})

- Scaling as a function of T_{targ} [4]

Calculated L_{INT} from ADAS data



Impurity line radiation (f_{power}) [5]

- **Hyp :** convection transport

$$f_{power} = 1 - \sqrt{1 - 2\kappa_0 \left(\frac{n_{up} T_{up}}{q_{\|,up}}\right)^2 L_{INT}}$$

- **Hyp :** negligible recycling effect f_{power}

$$L_{INT}(T_{up}, \tau_i) = \sum_i^{imp} f_i \int_0^{T_{up}} L_{Z,i}(T, \tau_i) \sqrt{T} dT$$

With τ_i the SOL impurity confinement time

Choice of impurity

Impurity	Z	P_{net}	$f_{L\text{-}H}$
Argon (Ar)	18	595 MW	**1.43**
Xenon (Xe)	54	**782 MW**	1.16

Heavier impurities improves the performances but makes the access to H-mode more difficult

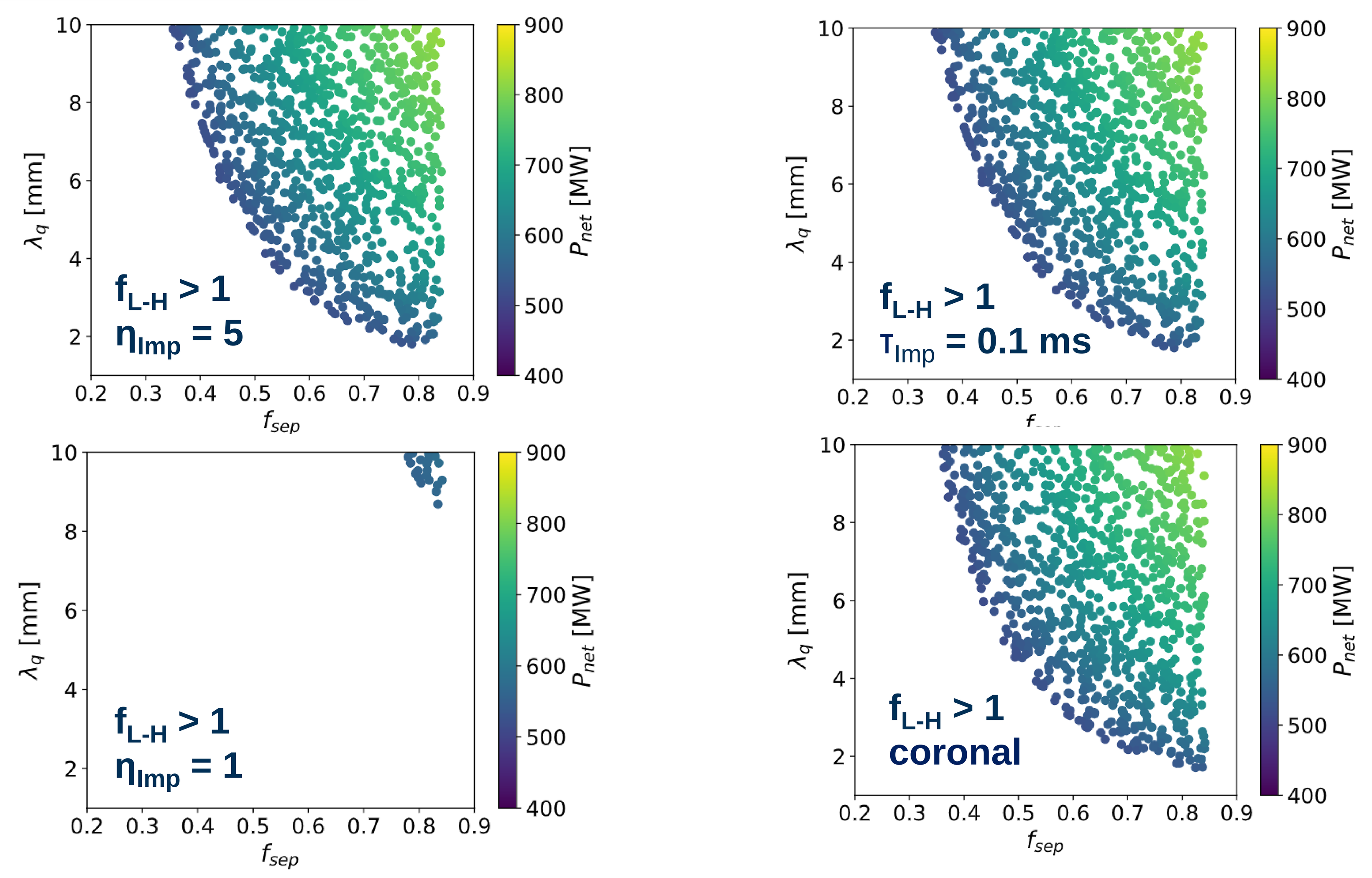
Argon impurity

- Less core line radiation
  Larger separatrix power for H mode ($f_{L\text{-}H}$)
- Accessible properties

Xenon impurity

- Good dilution / radiation ratio
  → Better fusion power
- But : Strong sputtering
  (not captured in this analysis)

Impurity transport



Important effect of SOL to core impurity transport on both H-mode access window and performances

Almost no effect of SOL impurity transport on both performances and H mode requirement

DEMO (2015) design parametrisation

Global design parameters [6]

Input name	Value
Minor/major radius (a_{min}/R_{maj})	2.93/9.01 m
Toroidal filed on axis (B_T)	5.66 T
95% flux safety factor (q_{95})	3.25
Up/low elongation	1.7/2.0
Greenwald/H fract (f_{GW} / f_H)	1.2/1.1
Heating power (P_{heat})	50 MW

Considered output

- Net electric power production : P_{net}
- L-H power threshold fraction [7] :
  $f_{L\text{-}H} = P_{sep} / P_{L\text{-}H,\ martin}$

SOL parameters

Input name	Value
Max. divertor heat flux (q_{peak})	10 MW.m^{-2}
Maximum plasma electronic temperature on target (T_{targ})	5 eV
SOL/core impurity fraction ratio (η_{Imp})	5
Upstream power length (λ_q)	3 mm
Greenwald separatrix density fraction ($f_{sep} = \frac{n_{sep}}{n_{GW} f_{GW}}$)	0.75
SOL impurity confinement time (τ_{Imp})	0.1 ms
Seeding impurity	Argon
No tungsten impurity considered	

References

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