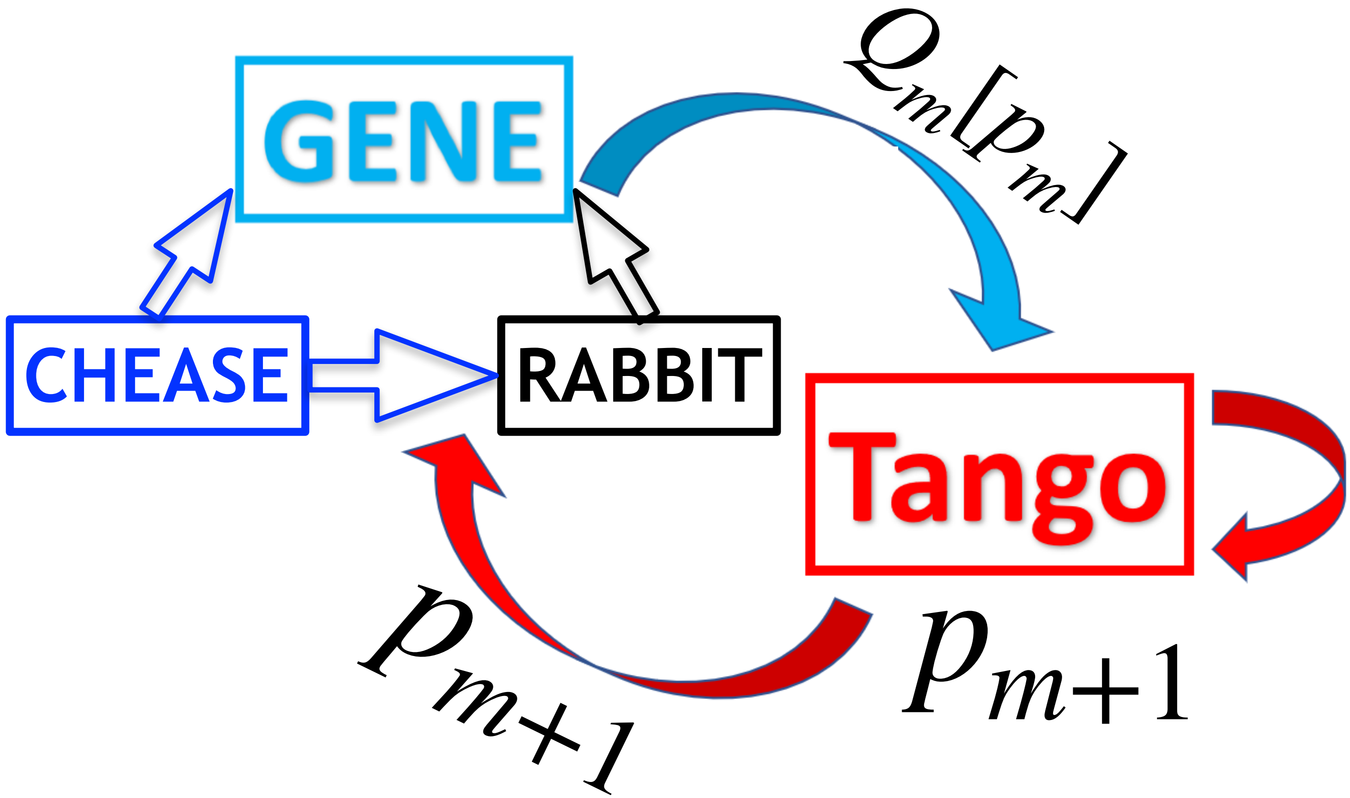
Bringing gyrokinetic simulations to transport time scale

GENE-Tango coupling

(i) GENE evaluates turbulence levels for given pressure profile

(ii) Tango evaluates new plasma profiles consistent with given turbulence levels and experimental sources.

(iii) New profiles transferred back to GENE and the process is repeated.



Transport solver Tango: basic equations

1D transport equation

- Macroscopic profiles are constant on magnetic flux surfaces

$$\frac{3}{2}A\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}AQ=AS$$

J. Parker et al. NF 2018
A. Shestakov et al. JCP 2003

A: Area flux-surface

$Q = \langle Q \cdot \nabla x \rangle$: Turbulent fluxes

S: Sources

- subscript ***m***: transport time step index; ***l***: iteration index within a time step

$$\frac{3}{2}A\frac{p_{m,l}-p_{m-1}}{\Delta t}=\frac{\partial}{\partial x}(AQ_{m,l}[p_{m,l}])+AS_m$$

- Turbulent fluxes taken as **time-average quantities** over many turbulent time steps (in the saturated phase) $\Delta\tilde{t}$ and the pressure profile is evolved by the macroscopic time step Δt

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$$\frac{3}{2}A\frac{p_{m,l} - p_{m-1}}{\Delta t} = \frac{\partial}{\partial x}(AQ_{m,l}[p_{m,l}]) + AS_m$$

- Q is the sum of diffusive and convective contributions

$$Q_{m,l} = -D_{m,l-1}\frac{\partial p_{m,l}}{\partial x} + c_{m,l-1}p_{m,l}$$

Transport solver Tango: basic equations

- There is freedom in the splitting of the turbulent flux Q between D and c

$$D_{m,l-1} = -\frac{\theta_{l-1} Q[p_{m,l-1}]}{\frac{\partial p_{m,l-1}}{\partial x}} \qquad c_{m,l-1} = \frac{(1-\theta_{l-1}) Q[p_{m,l-1}]}{p_{m,l-1}}$$

- θ denotes the nature of the turbulent fluxes, i.e. diffusive and/or convective, assuming plasma turbulence mainly diffusive $\rightarrow \theta \sim 1$
- Diffusion coefficients depending on $\partial p_{m,l-1}/\partial x$ makes the iteration numerically unstable. It is stabilised by adding the relaxation coefficient α to D and c

$$\bar{Q}_{m,l-1} = \alpha Q[\hat{p}_{m,l-1}] + (1-\alpha)\bar{Q}_{m,l-2}$$

$$\bar{p}_{m,l-1} = \alpha p_{m,l-1} + (1-\alpha)\bar{p}_{m,l-2}$$

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Transport solver Tango: basic equations

- Tango solves iteration equation within an implicit timestep advance of a transport equation: nonlinear equation for the time-advanced (backward Euler step)

$$\frac{3}{2}A\frac{p_{m,l}-p_{m-1}}{\Delta t}=\frac{\partial}{\partial x}\left(AD_{m,l-1}\frac{\partial p_{m,l}}{\partial x}-Ac_{m,l-1}p_{m,l}\right)+AS$$

- Each coefficient is evaluated at the previous iterate ***l*-1** and the transport equation is linear in the unknown $p_{m,l}$

$$M_{m,l-1}p_{m,l}=g$$

***l*-1 terms** **Sources + terms p_{m-1}**

- When the iteration in ***l*** converges, the representation for the flux (right-hand side) is equal to the actual turbulent flux Q (left-hand side)

$$Q_{m,l}=\int dV(P_{ICRH}+P_{NBI}+\ldots)$$