Full-F Multi-Species Gyrokinetic Collision Operator
Application to GYSELA

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INTRODUCTION

Although weak, collisions are essential for many reasons in Fusion plasmas:

- Regularization of the distribution function in velocity space
- Relaxation towards the Maxwellian
- Exchange of momentum and energy between species
- Govern large scale flows (ion poloidal flow, Zonal Flow damping)
- Neoclassical transport, essential for impurities

This poster:

- Linearized full-F multi-species collision operator in gyrokinetic framework
- Implementation & benchmark in GYSELA (Gyrokinetic Semi-Lagrangian)

A linearized operator

Collision operator linearized around unshifted Maxellian F_{M0}

$$C_{ab}(F_a,F_b) = C^0_{ab}(F_{M0a},F_{M0b}) + C^1_{ab}(F_a,F_b)$$

$$C^0_{ab}(F_{M0a},F_{M0b}) = \frac{T_b - T_a}{T_b}\frac{m_a v^2}{2T_a}\nu_{E,ab}F_{M0a}$$

$$C^1_{ab}(F_a,F_b) = C_{v,ab}(F_a) + C_{d,ab}(F_a) + C_{\parallel,ab}(F_a,F_b)$$

$$C_{\parallel,ab}(F_a,F_b) = -\nu_{s,ab}(v)\frac{m_a}{T_a}v_\parallel\left(U_{\parallel d,a} - U_{\parallel ba}\right)F_{M0a} \qquad g_a = f_a - \frac{m_a v_\parallel U_{\parallel d,a}}{T_a}$$

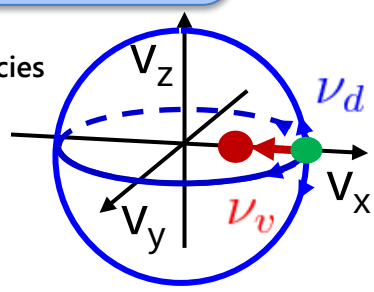
$$C_{v,ab}(F_a) = \frac{1}{2B^\star_\parallel v_\perp}\frac{\partial}{\partial v_\perp}\left[B^\star_\parallel F_{M0a}\nu_{v,ab}v_\perp^2\left(v_\perp\frac{\partial g_a}{\partial v_\perp} + v_\parallel\frac{\partial g_a}{\partial v_\parallel}\right)\right] + \frac{1}{2B^\star_\parallel}\frac{\partial}{\partial v_\parallel}\left[B^\star_\parallel F_{M0a}\nu_{v,ab}v_\parallel\left(v_\perp\frac{\partial g_a}{\partial v_\perp} + v_\parallel\frac{\partial g_a}{\partial v_\parallel}\right)\right]$$

$$C_{d,ab}(F_a) = \frac{1}{2B^\star_\parallel v_\perp}\frac{\partial}{\partial v_\perp}\left[B^\star_\parallel F_{M0a}\nu_{d,ab}v_\perp v_\parallel\left(v_\parallel\frac{\partial g_a}{\partial v_\perp} - v_\perp\frac{\partial g_a}{\partial v_\parallel}\right)\right] + \frac{1}{2B^\star_\parallel}\frac{\partial}{\partial v_\parallel}\left[B^\star_\parallel F_{M0a}\nu_{d,ab}v_\perp\left(-v_\parallel\frac{\partial g_a}{\partial v_\perp} + v_\perp\frac{\partial g_a}{\partial v_\parallel}\right)\right]$$

$C^0_{ab}(F_{M0a},F_{M0b})$ Energy exchange between species

$C_{\parallel,ab}(F_a,F_b)$ Momentum exchange " "

$C_{v,ab}(F_a) + C_{d,ab}(F_a)$ Diffusion in v-space



Parallelization issue: F projected on set of orthogonal (Laguerre) polynomials

$$F(\boldsymbol{r},v_\parallel,u,t) = F_{M0}\sum_l \alpha_{\ell,a}(\boldsymbol{r},v_\parallel,t)P_\ell(u) \qquad \text{with} \quad u = \frac{\mu B}{T}$$

⇒ $\mu = mv_\perp^2/2B$ derivatives replaced by integrals

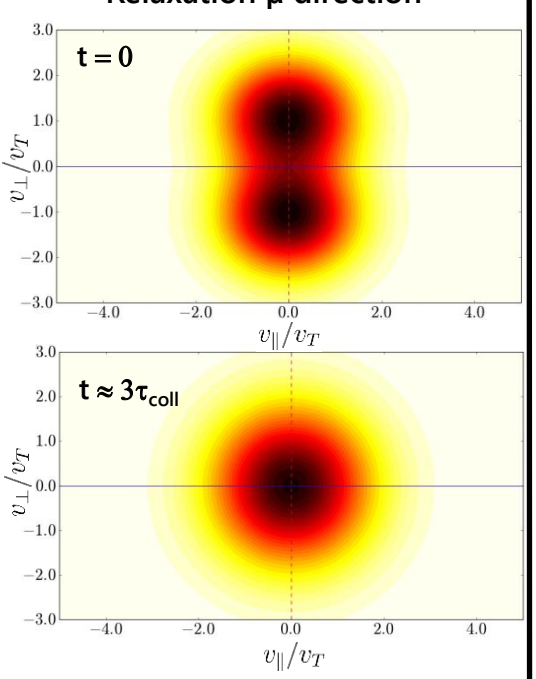
Tests of intrinsic properties of collision

Conservation of particles, total momentum and energy :

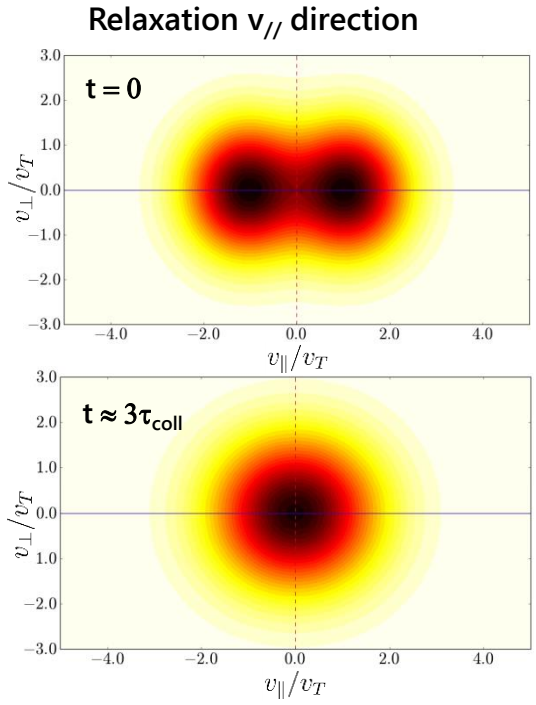
$$\frac{\Delta n}{n} \simeq 7\cdot 10^{-7} \qquad \Delta p_\parallel \simeq 10^{-9} \qquad \frac{\Delta E}{E} \simeq 6\cdot 10^{-6}$$

Relaxation toward a Maxwellian :

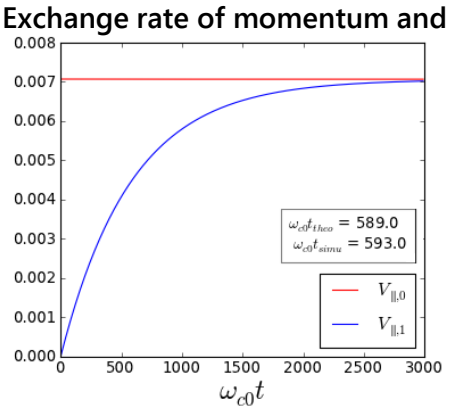
Relaxation μ direction



Relaxation $v_{//}$ direction

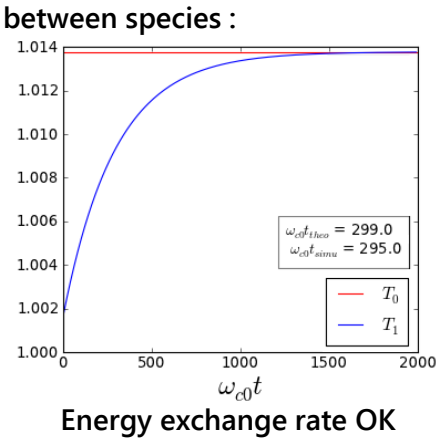


Exchange rate of momentum and energy between species :



Momentum exchange rate OK

$$\frac{d\ln\left(V_{\parallel a} - V_{\parallel b}\right)}{dt} = -\left(\nu_{ab} + \nu_{ba}\right)$$



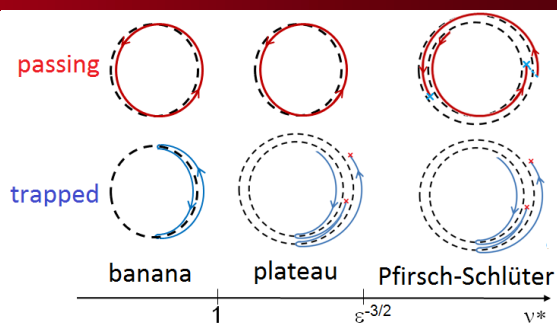
Energy exchange rate OK

$$\frac{d\ln\left(T_a - T_b\right)}{dt} = -2\frac{m_a\nu_{ab} + m_b\nu_{ba}}{m_a + m_b}$$

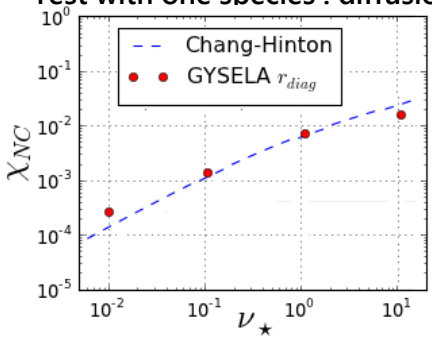
Neoclassical benchmark

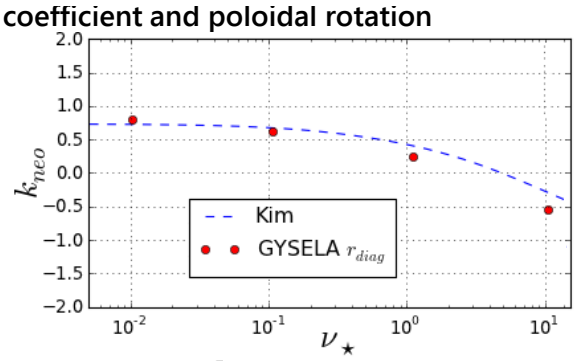
Neoclassical transport = enhanced collisional transport due to trajectories

Depends on collisionality regime $\nu_* = \nu_{coll} \times \tau_{transit}$

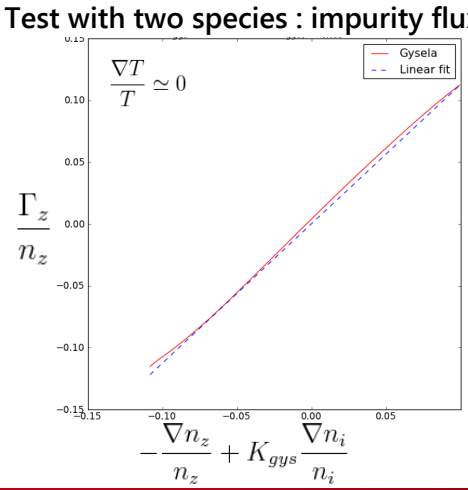


Test with one species : diffusion coefficient and poloidal rotation





Test with two species : impurity flux $\Gamma_z = -n_Z D_{gys}\left[\frac{\nabla n_z}{n_z} - K_{gys}Z\frac{\nabla n_i}{n_i} + H_{gys}Z\frac{\nabla T}{T}\right]$

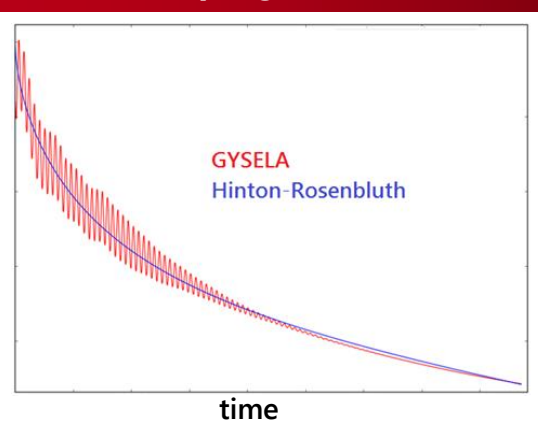


$$K_{gys} = 1.02 \pm 0.01$$

$$\frac{D_{gys}}{D_{theo}} \simeq 1.1$$

The screening factor H is under investigation

Collisional damping of zonal flows



Collisional damping rate in agreement with theoretical prediction

CONCLUSION

- New collision operator developed & implemented in GYSELA
- Many tests have been passed successfully : Conservations, H theorem, exchange rates between species, neoclassical transport at one species, collisional damping of zonal flows.
- Neoclassical tests for two species are under investigation. Results ok so far