Interacting Dark Energy: the role of microscopic feedback in the dark sector

based on arXiv: 1502.02531

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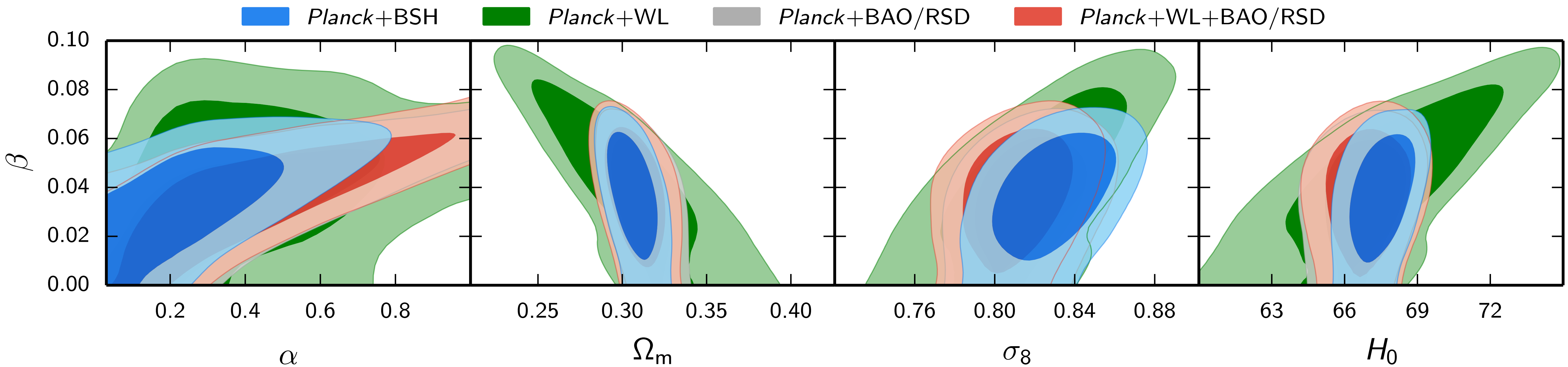
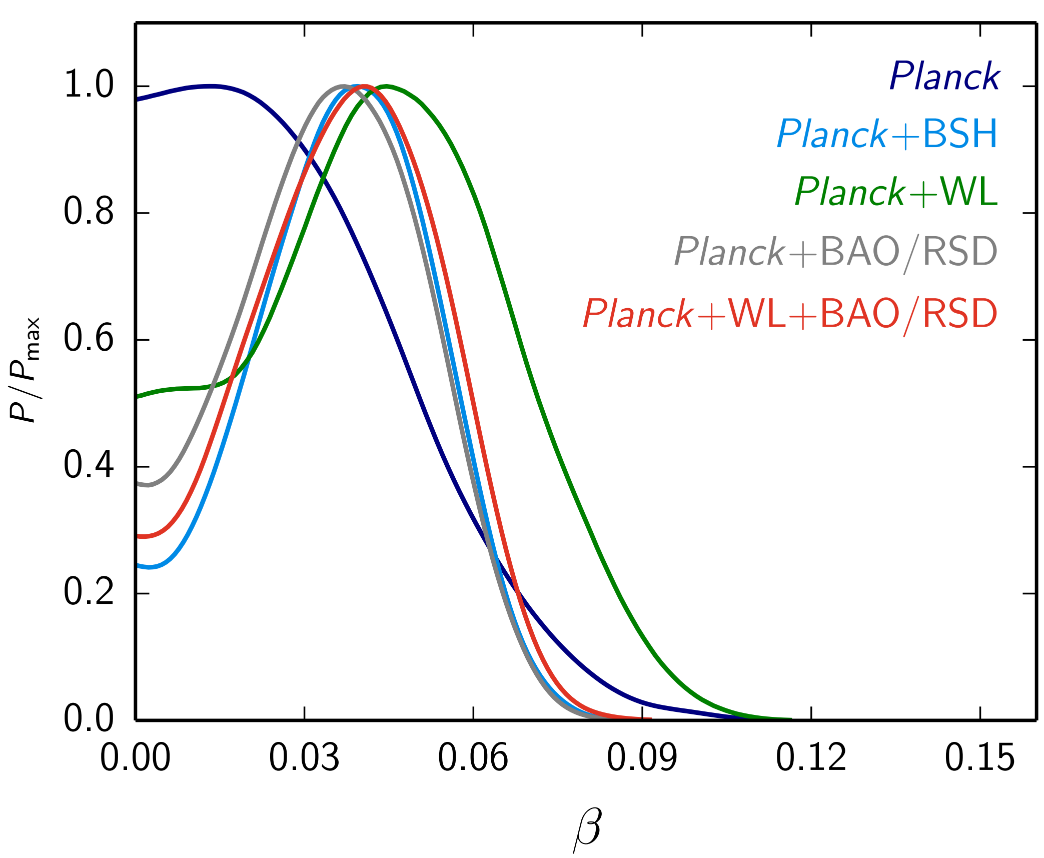
Planck 2015: coupled dark energy



Planck Collaboration, arXiv: 1502.01590



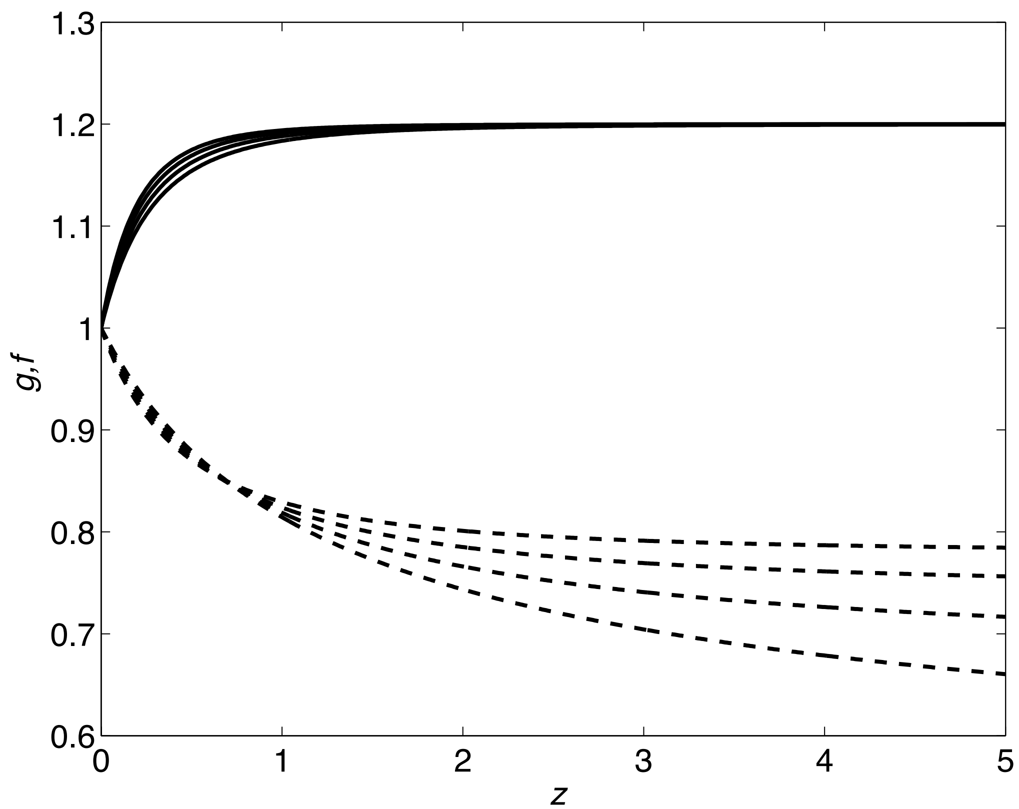
DE field ϕ:

$$m(\phi) \propto \exp(-\beta\phi)$$

$$V(\phi) \propto \phi^{-\alpha}$$

A positive coupling β (smaller Ω_m today) leads to a larger σ_8 and H_0.

Ignoring the DE-DM interaction could lead to an incorrect reconstruction of the DE equation of state

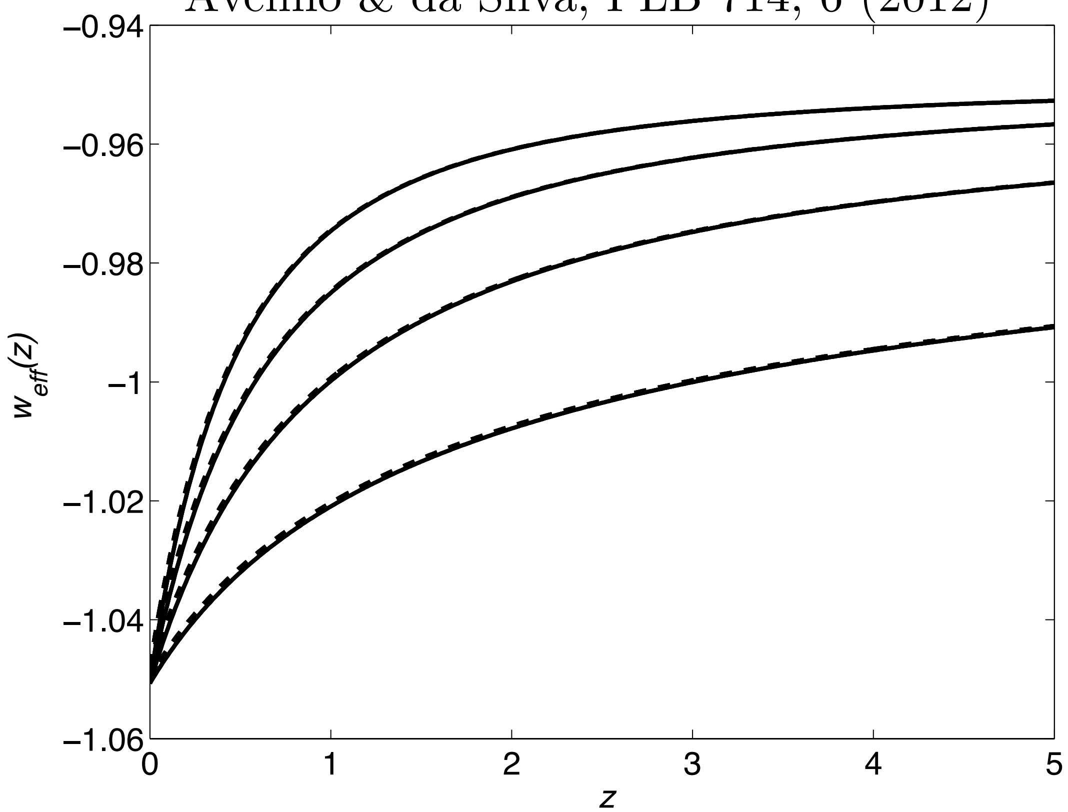


$$w = -0.95$$

$$\rho_m = \Omega_{m0} g(z)(1+z)^3$$

$$\rho_w = \Omega_{w0} f(z)(1+z)^{3(1+w)}$$

Avelino & da Silva, PLB 714, 6 (2012)



$w_{eff}(z)$ is obtained ignoring the interaction between DM and DE, assuming a perfect knowledge of $H(z)$ and of the matter density at recombination.

IDE model

$$S = \int d^2x \, \sqrt{-g} \, \mathcal{L}$$

$$\mathcal{L} = -\frac{1}{2}\partial_\mu \phi \partial^\mu \phi - \frac{1}{2}\partial_\nu \psi \partial^\nu \psi - W(\phi, \psi)$$

$$W(\phi, \psi) = U(\phi, \psi) + V(\phi)$$

$$U(\phi, \psi) = \frac{\lambda(\phi)}{4}(\psi^2 - \eta^2)^2$$

Equations of motion

$$\Box\psi = \frac{\partial U}{\partial\psi}$$

$$\Box\phi = \frac{dV}{d\phi} - 2\beta U$$

$$\beta \equiv -\frac{1}{2}\frac{d\ln\lambda}{d\phi}$$

1+1 dimensional Minkowski space:

$$\ddot{\psi} - \psi'' = -\frac{\partial U}{\partial\psi}$$

$$\ddot{\phi} - \phi'' = -\frac{dV}{d\phi} + 2\beta U$$

Energy-momentum

$$T^{\mu\nu} = \frac{2}{\sqrt{-g}} \frac{\delta(\mathcal{L}\sqrt{-g})}{\delta g_{\mu\nu}} = 2\frac{\delta \mathcal{L}}{\delta g_{\mu\nu}} + g^{\mu\nu}\mathcal{L}$$

$$T^{\mu\nu} = T^{\mu\nu}_{DM} + T^{\mu\nu}_{DE}$$

$$T^{\mu\nu}_{DM} = \partial^\mu \psi \partial^\nu \psi - \frac{g^{\mu\nu}}{2}\left(\partial_\alpha \psi \partial^\alpha \psi + 2U(\phi, \psi)\right)$$

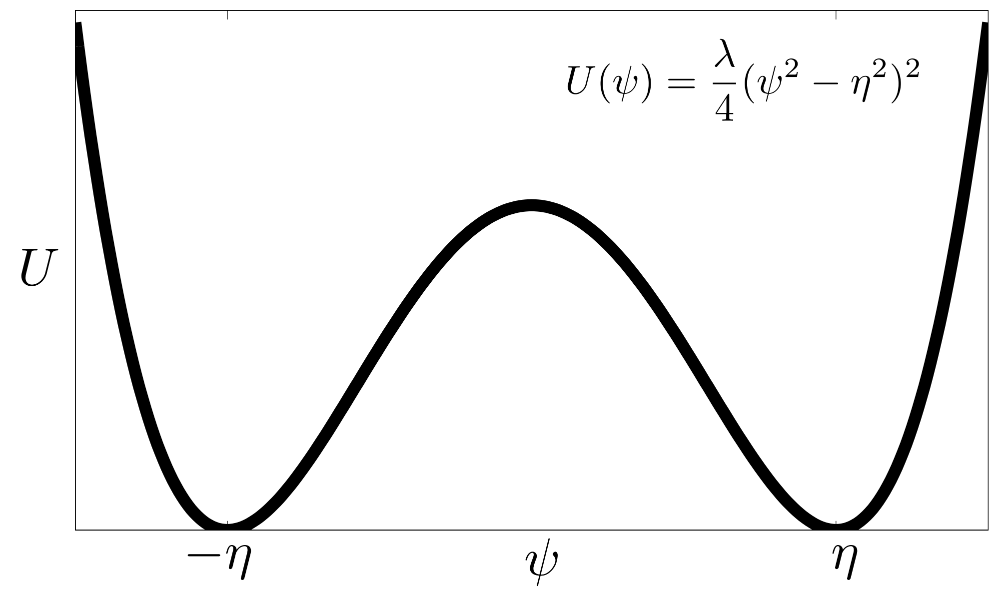
$$T^{\mu\nu}_{DE} = \partial^\mu \phi \partial^\nu \phi - \frac{g^{\mu\nu}}{2}\left(\partial_\alpha \phi \partial^\alpha \phi + 2V(\phi)\right)$$

$$\nabla_\nu T^{\mu\nu}_{DM} = Q^\mu$$

$$\nabla_\nu T^{\mu\nu}_{DE} = -Q^\mu$$

$$Q^\mu = 2\beta U(\phi, \psi)\partial^\mu \phi$$

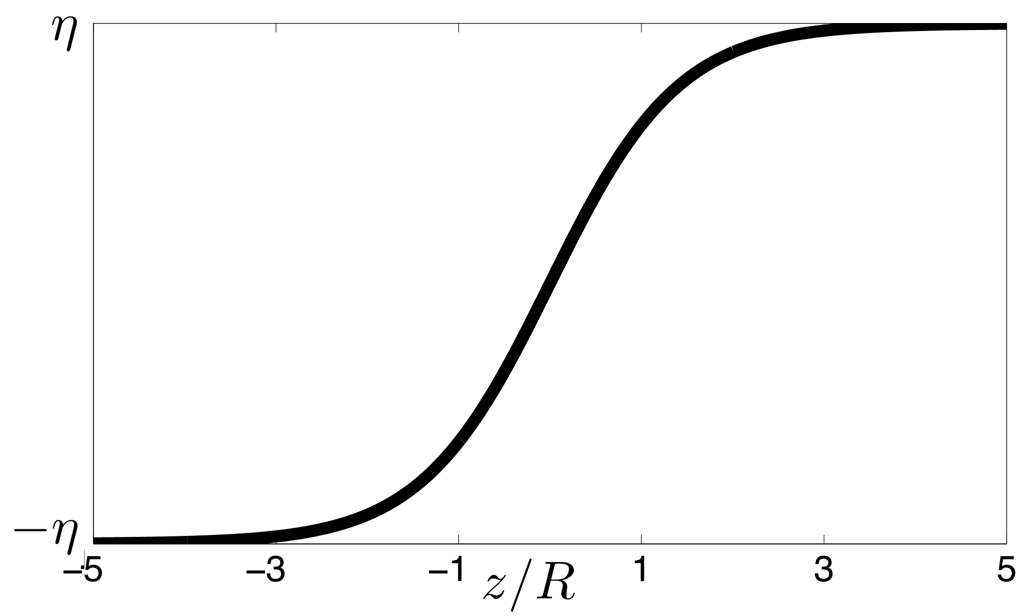
DM particles I



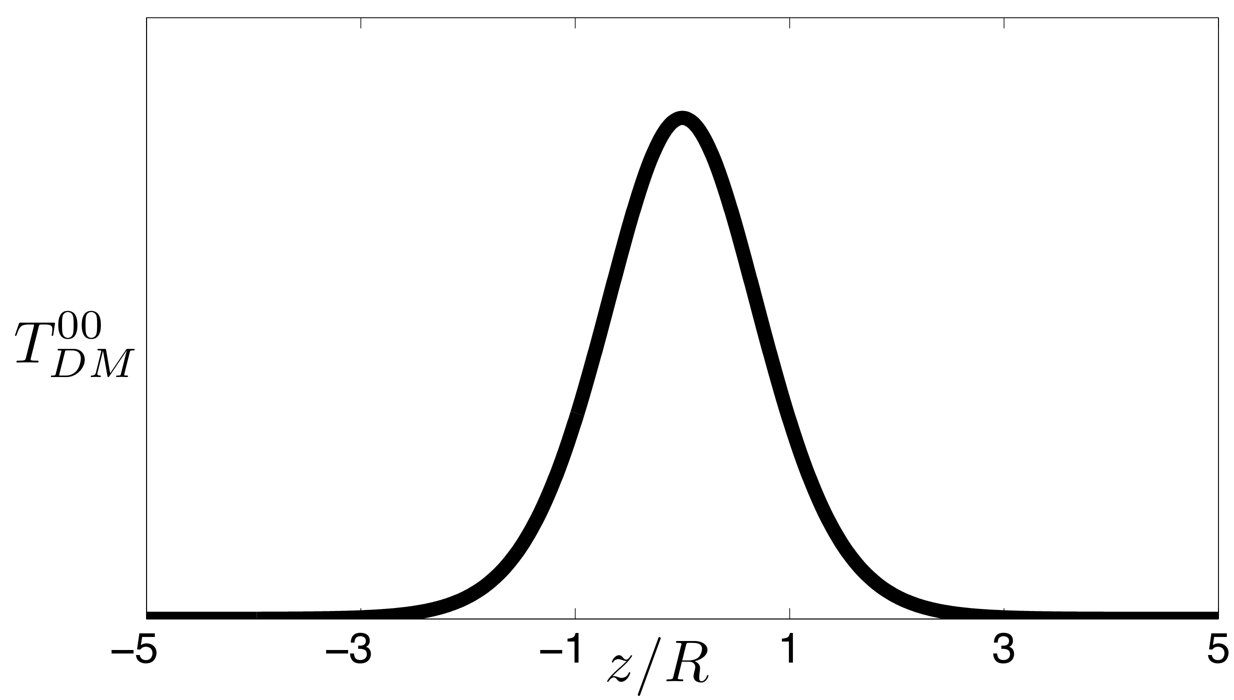
$$\lambda = \text{const}$$

$$\psi'' = \frac{dU}{d\psi} \quad \Rightarrow \quad \frac{\psi'^2}{2} = U$$

$$\psi = \pm\eta \tanh\left(\frac{z}{\sqrt{2}R}\right) \qquad R = \lambda^{-1/2}\eta^{-1}$$



DM particles II



$$T^{zz}_{DM} = 0$$

$$m_\psi = \int_{-\infty}^{\infty} T^{00} dz = \frac{2\sqrt{2}}{3} \lambda^{1/2} \eta^3$$

$$\lambda = \lambda(\phi) \quad \Rightarrow \quad \beta \equiv -\frac{1}{2} \frac{d \ln \lambda}{d\phi} = -\frac{d \ln m_\psi}{d\phi}$$

Force on DM particles

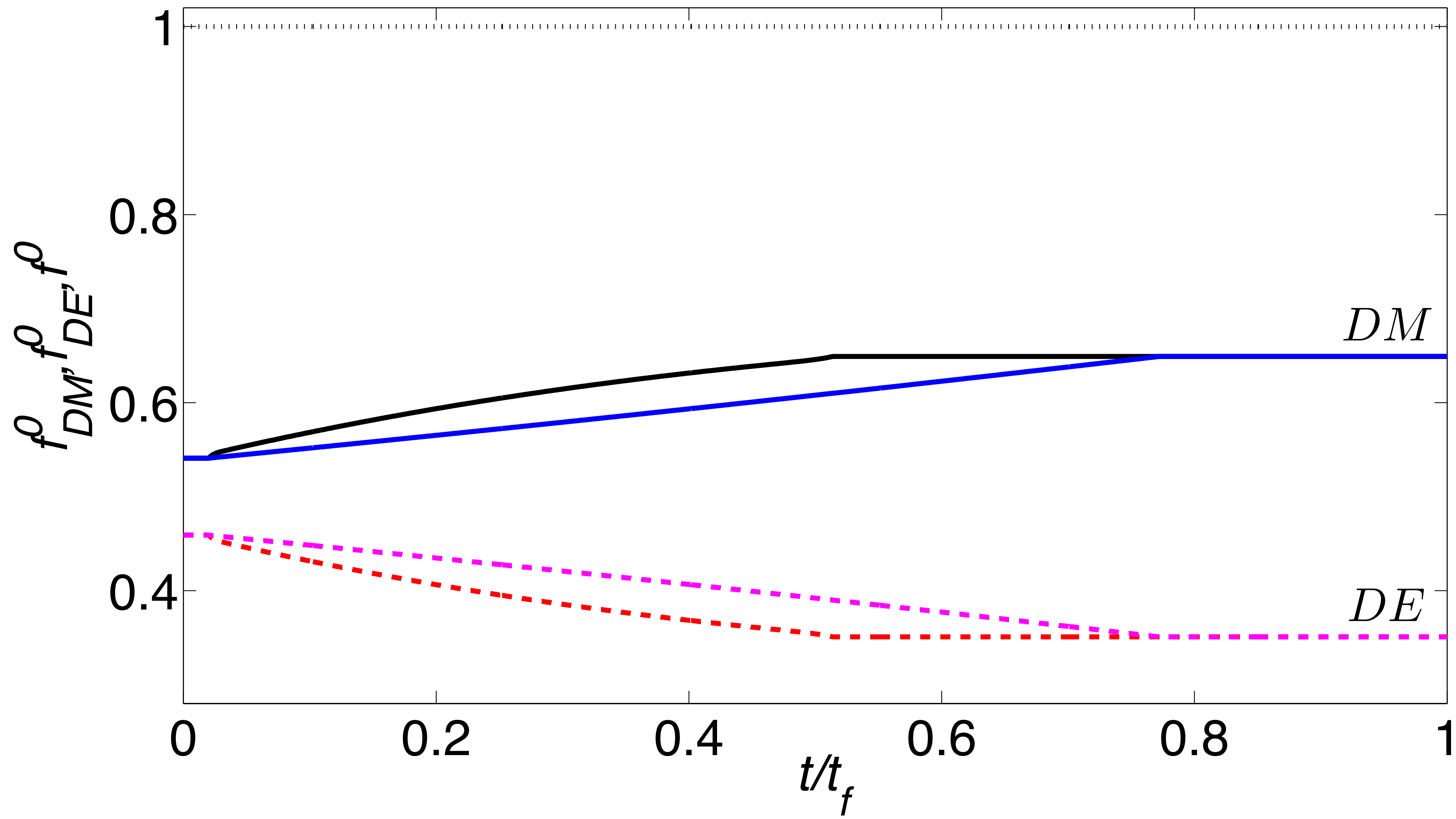
1+1 dimensional Minkowski space:

$$\frac{dE}{dt} = \int \partial_0 T^{00}_{DM} dz = 2\int \beta U(\phi,\psi)\partial^0\phi dz \sim -\frac{\beta m_\psi \dot{\phi}}{\gamma}$$

$$F = \frac{dp}{dt} = \int \partial_0 T^{0z}_{DM} dz = 2\int \beta U(\phi,\psi)\partial^z\phi dz \sim \frac{\beta m_\psi \phi'}{\gamma}$$

In general:

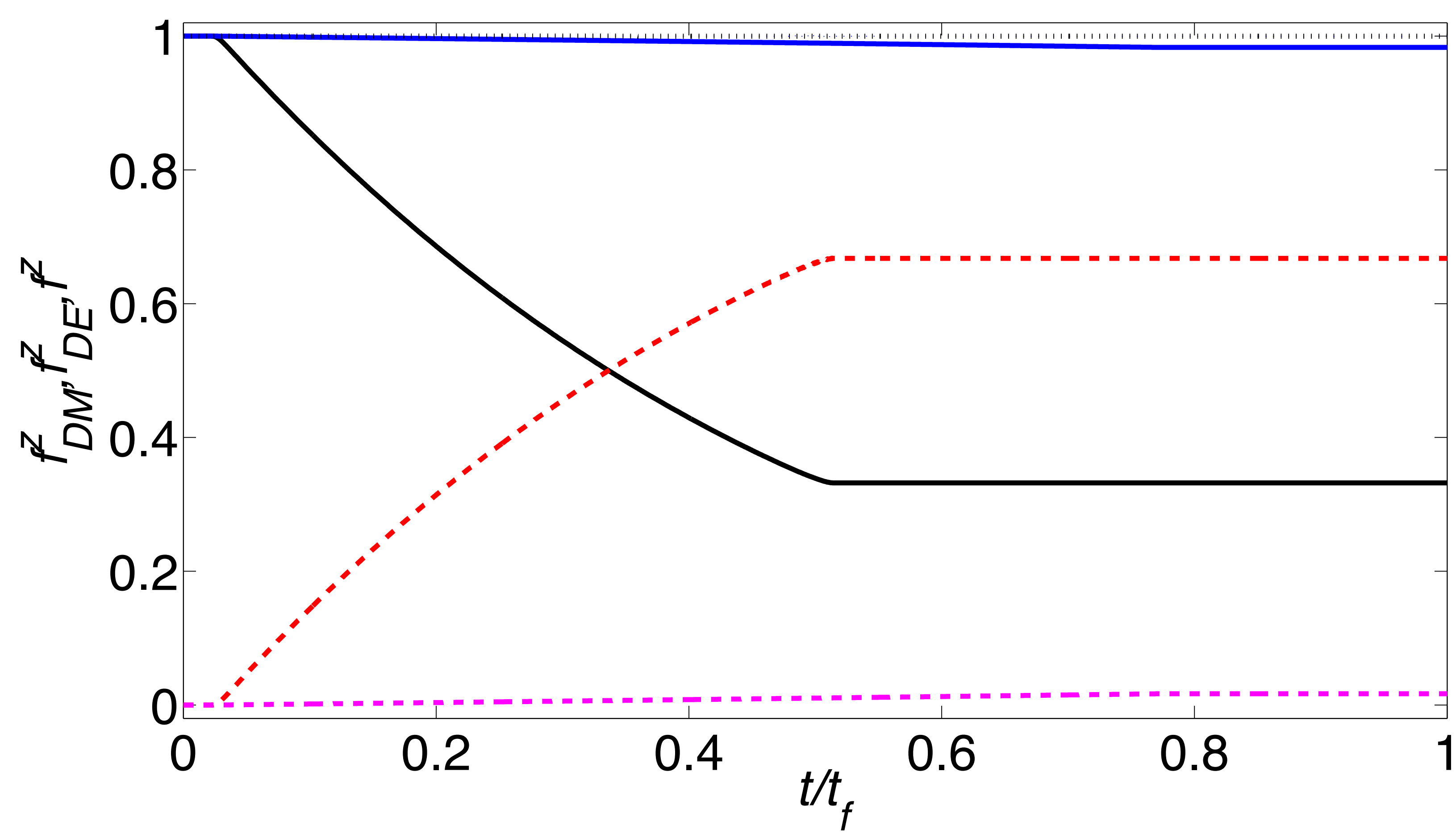
$$\frac{dp^\alpha}{d\tau} = \left(\nabla_\beta p^\alpha\right) u^\beta \sim m_\psi \beta \partial^\alpha \phi$$



$$f^0_{DM} \equiv \frac{\int T^{00}_{DM}\, dz}{\int T^{00}_{t=0}\, dz}$$

$$f^0_{DE} \equiv \frac{\int T^{00}_{DE}\, dz}{\int T^{00}_{t=0}\, dz}$$

$$f^0 \equiv f^0_{DM} + f^0_{DE}$$



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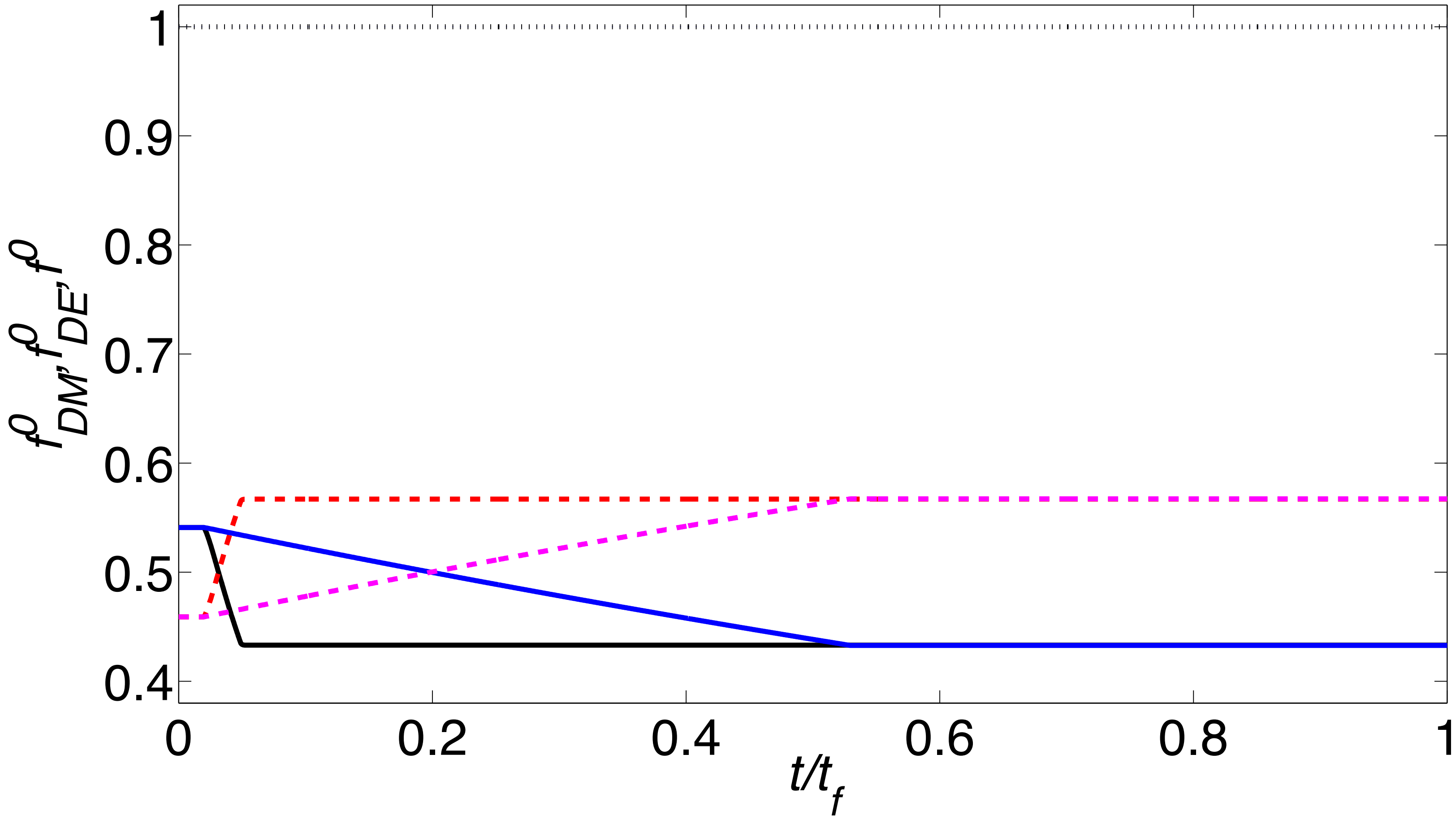

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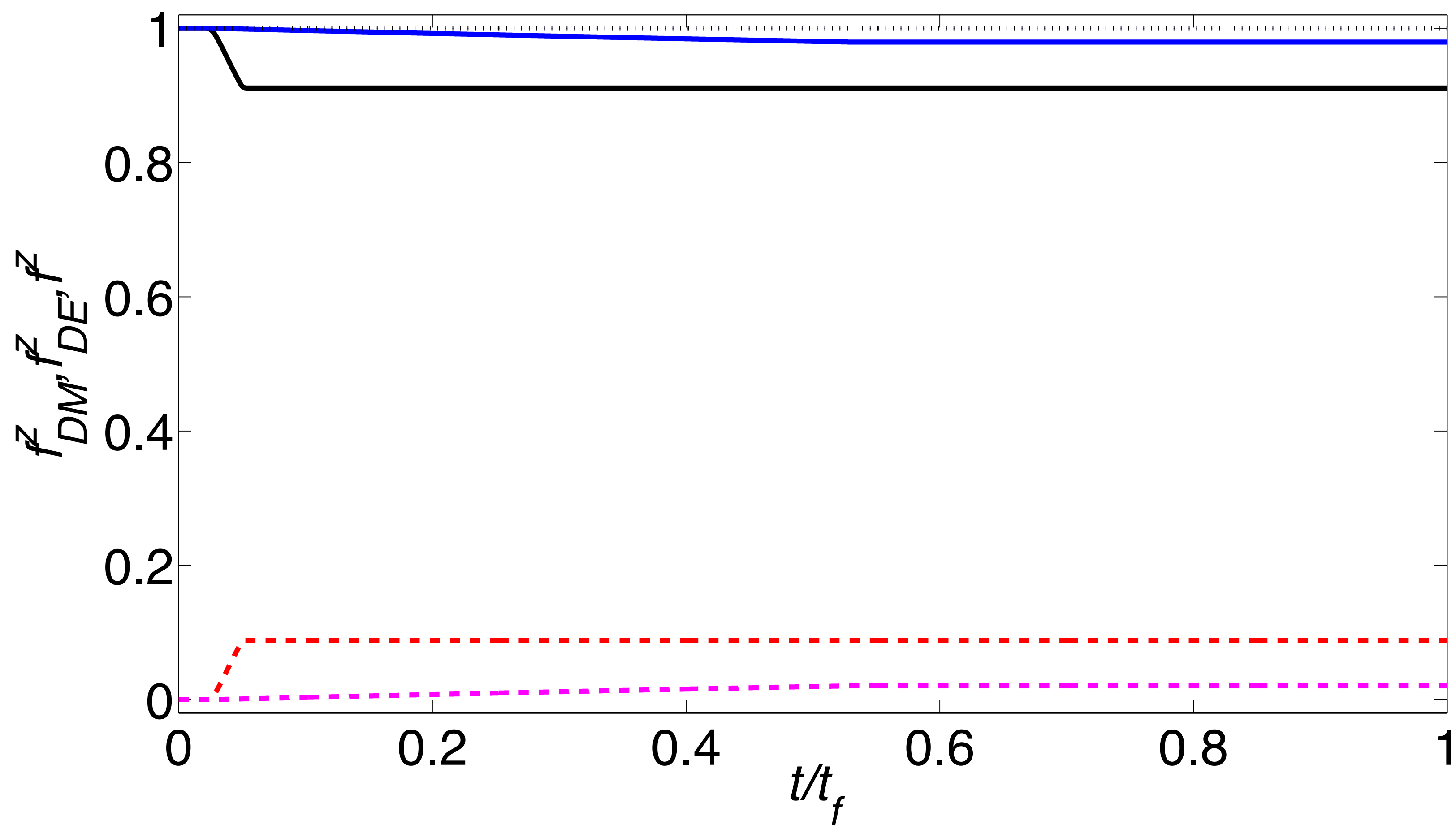

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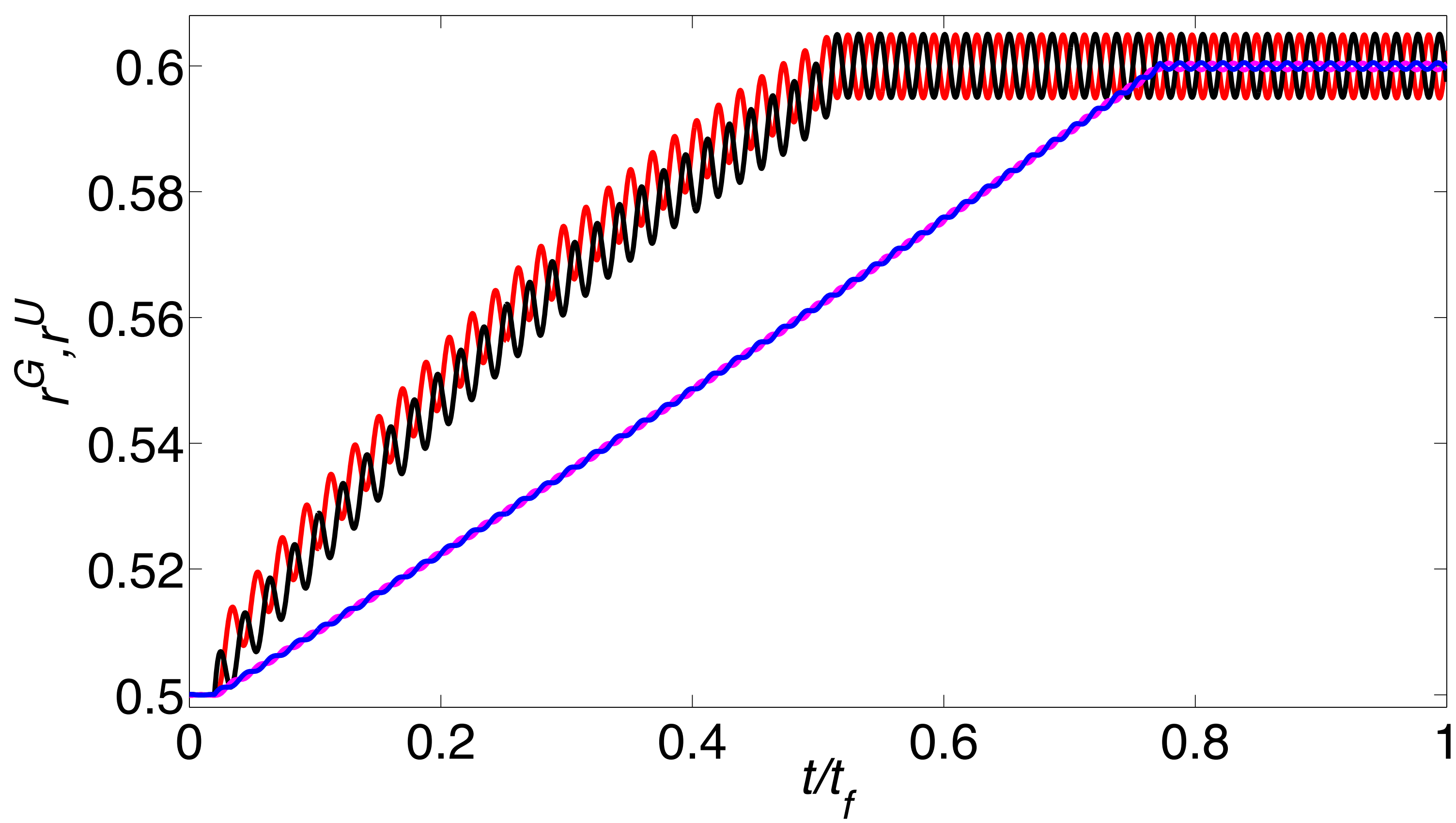

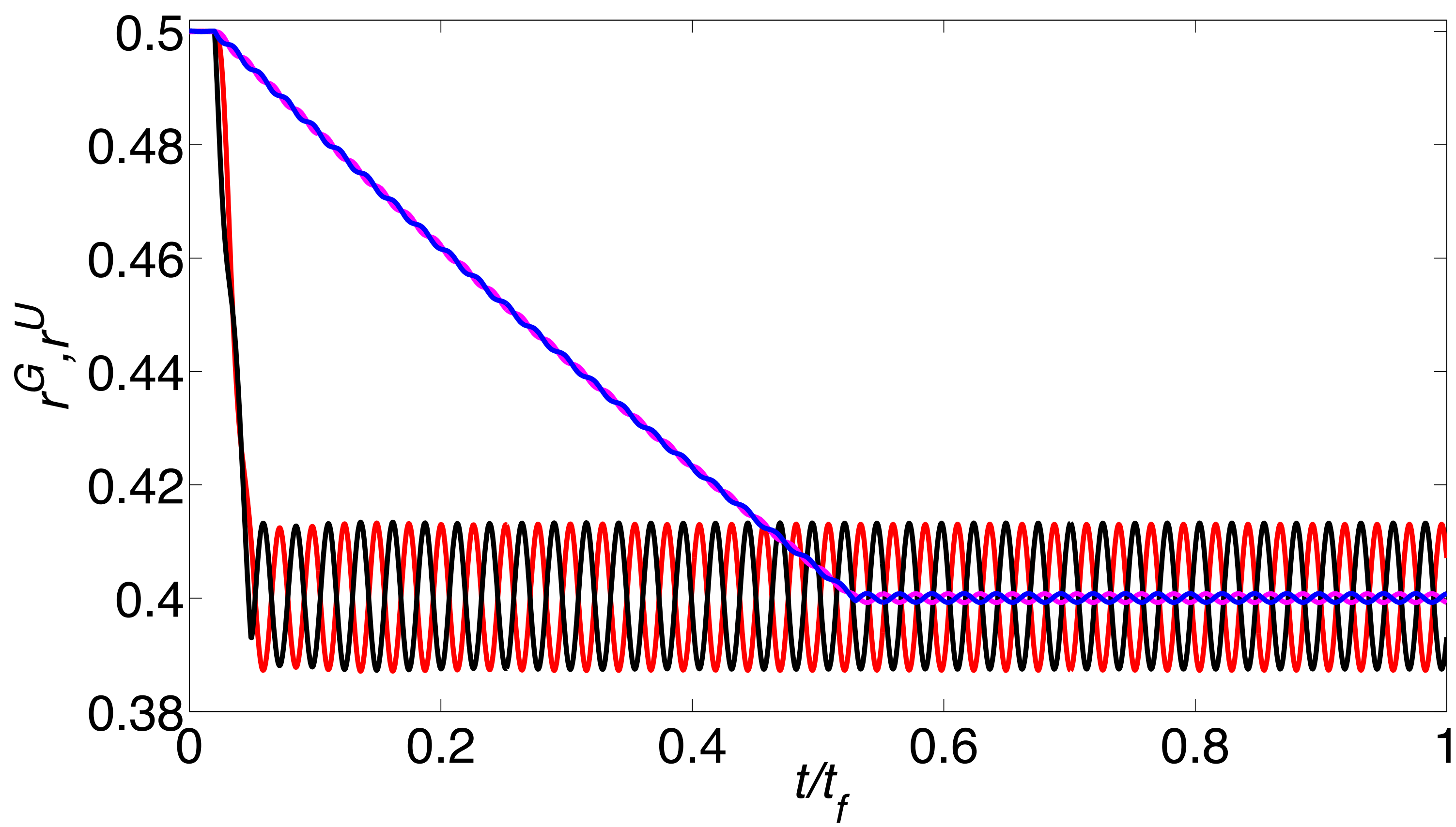

$$r^G \equiv \frac{\int \psi'^2 \, dz}{2 \int T^{00}_{DM|t=0} \, dz}$$

$$r^U \equiv \frac{\int U \, dz}{\int T^{00}_{DM|t=0} \, dz}$$

Summary

- the dynamics of the DM particles is sensitive to local changes in the gradient of DE scalar field due to microscopic feedback;

- in 1+1 dimensions microscopic feedback effects are particularly relevant when:

$$\left|\frac{d\rho_\psi}{dt}\right| R \gtrsim \frac{\dot{\phi}^2}{2}\,, \qquad\qquad \rho_\psi \equiv \frac{3m_\psi}{4\pi R^3}$$

- Extrapolating to 3+1 dimensions, we expect microscopic feedback to be particularly relevant for DM masses:

$$m_\psi \gtrsim m_* \equiv \frac{\rho_\phi(w_\phi + 1)R^2}{\beta\dot{\phi}}$$

Thank you

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