TWO FLUID GAS AND DUST MIXTURES IN SPH

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One of the most challenging aspects of numerical simulations of dust and gas mixtures is the often enormous difference between gas and dust evolutionary time scales. Whenever the dust stopping time becomes much smaller than the gas evolutionary time scale, explicit/implicit integration schemes require an excessively large number of time-steps, and none of the previous SPH schemes in the two fluid approach (Monaghan & Kocharyan 1995 and 1997; Maddison, Humble & Murray 2003; Rice et al. 2004; Barriere-Fouchet et al. 2005, Laibe & Price 2012) have addressed this problem. In the present work, a method to avoid the time integration of the small dusty grains evolution equations, in the Smoothed Particle Hydrodynamics (SPH) two fluid approach is proposed. By assuming a very simple exponential decay model for the relative velocity between the gas and dust components, all the effective characteristics of the drag force can be reproduced. Taking as a reference the recent work of Laibe & Price (2011/12) a series of tests have been performed in order to compare the accuracy of the present method with a standard integration method.

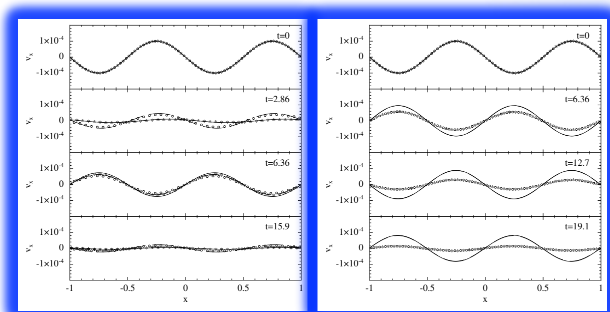
- For small dust grains, the effect of the drag force can be modeled as an exponential decay of the relative velocity between the dust and gas components:

$$\vec{v}_D(t+\delta t)=\vec{v}_D(t)-\nu\sum_j^{Gas} m_j\left(\frac{\xi_{Dj}}{\rho_j}\right)(\vec{v}_{Dj}\cdot\hat{r}_{Dj})\hat{r}_{Dj}\bar{D}_{Dj}$$

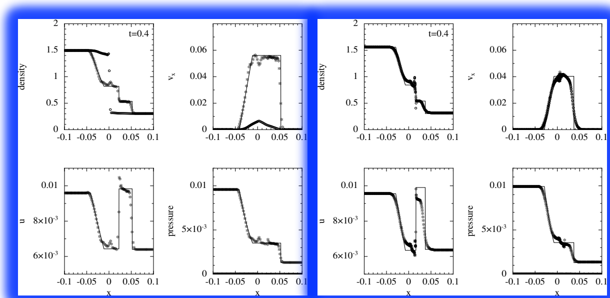
$$\vec{v}_G(t+\delta t)=\vec{v}_G(t)+\nu\sum_k^{Dust} m_k\left(\frac{\xi_{kG}}{\rho_G}\right)(\vec{v}_{kG}\cdot\hat{r}_{kG})\hat{r}_{kG}\bar{D}_{kG}$$

$$\xi_{DG}=\left(\frac{\rho_G}{\rho_G+\rho_D}\right)(1-e^{-(\delta t/Nt_s)})$$

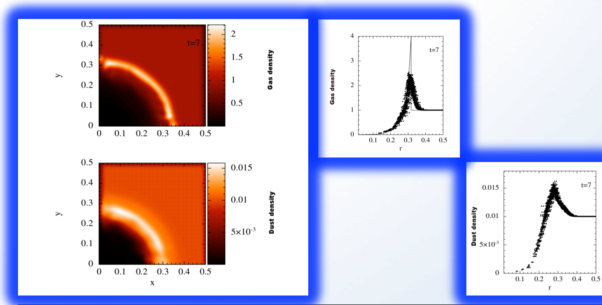
- The method, iteratively removes a fraction of the relative velocity between the gas and dust SPH particles along the line of sight joining them.
- This way, linear and angular momentum conservation, together with energy dissipation can be guaranteed.
- The method has been able to obtain, in all of the tested cases, the same results as the explicit/implicit integration scheme of Laibe & Price (2012)
- The method needs to be iteratively applied a certain number of times per SPH time-step in order to guarantee a correct calculation of the relative velocities between the gas and dust components. However, because it avoids the need for acceleration recalculations, it is many times faster than implicit/explicit methods for highly coupled dust grains.
- As any SPH two fluid method, produces an excess of dissipation when drag forces are very intense and dust-to-gas ratios are close to unity.
- Work is still in progress, but even in the advent of not being able to overcome this limitation, the method can still be applied to many astrophysical scenarios, where dust-to-gas ratios are typically lower than unity.



- Time evolution of the dust (open circles) and gas (stars) components of a dusty sound wave (with a dust-to-gas ratio equal to one) in a low drag regime (left panel) and a high drag regime (right panel). Solid (gas) and dashed (dust) lines correspond to the theoretical solution of the problem (Laibe & Price 2011). Due to the limited resolution in the x direction, and in complete agreement with Laibe & Price (2012), an excess of dissipation is found in the high drag regime.



- Different snapshots of the result of a three-dimensional dusty shock-tube problem with a dust-to-gas ratio of unity in a low drag regime (left panel), and a high drag regime (right panel). Stars represent the gas component of the fluid, while open circles represent the dust component. Solid lines represent the stationary solution of the problem. Note that, despite having used a total number of 2000x20x20 particles, the results in the high drag regime are still far from correct due to the effect of over dissipation, again in complete agreement with Laibe & Price (2012).



- Result of a three-dimensional Sedov problem with a dust-to-gas ratio of 0.01 in a high drag regime. Solid lines represent the self-similar solution of the Sedov problem. In this case, having used a total number 50x50x50 particles, no over dissipation is appreciated due to the low dust-to-gas ratio.

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(*) All figures have been created using SPLASH (Price 2007), a SPH visualization tool publically available at: http://users.monash.edu.au/~dprice/splash/

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