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ARTIFICIAL VISCOSITY IN STARSMASHER

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Subject headings:

Our SPH evolution equations are described by Gaburov et al. (2010), but with a different AV implementation. In particular, the AV contribution to the acceleration of particle i is calculated as

$$\dot{\mathbf{v}}_{\mathrm{AV},i} = -\sum_j m_j \left[\Pi_{ij} \nabla_i W_{ij}(h_i) + \Pi_{ji} \nabla_i W_{ij}(h_j)\right]/2\,. \tag{1}$$

We use the AV form

$$\Pi_{ij} = 2\frac{P_i}{\rho_i^2}\left(-\alpha\mu_{ij} + \beta\mu_{ij}^2\right)\,, \tag{2}$$

where

$$\mu_{ij} = \begin{cases} \dfrac{(\mathbf{v}_i - \mathbf{v}_j)\cdot(\mathbf{r}_i - \mathbf{r}_j)}{c_i|\mathbf{r}_i - \mathbf{r}_j|} f_i\,, & \text{if } (\mathbf{v}_i - \mathbf{v}_j)\cdot(\mathbf{r}_i - \mathbf{r}_j) < 0\,; \\ 0\,, & \text{if } (\mathbf{v}_i - \mathbf{v}_j)\cdot(\mathbf{r}_i - \mathbf{r}_j) \geq 0\,. \end{cases} \tag{3}$$

Here c_i is the sound speed at the location $\mathbf{r}_i$ of particle i. The Balsara switch f_i for particle i is defined by

$$f_i = \frac{|\nabla\cdot\mathbf{v}|_i}{|\nabla\cdot\mathbf{v}|_i + |\nabla\times\mathbf{v}|_i + \eta' c_i/h_i}\,, \tag{4}$$

with $\eta' = 10^{-5}$ preventing numerical divergences The function f_i approaches unity in regions of strong compression ($|\nabla\cdot\mathbf{v}|_i >> |\nabla\times\mathbf{v}|_i$) and vanishes in regions of large vorticity ($|\nabla\times\mathbf{v}|_i >> |\nabla\cdot\mathbf{v}|_i$). Consequently, our evolution equations have the advantage that the artificial viscosity (AV) is suppressed in shear layers. We note that the AV term is not symmetric under interchange of the indices i and j (that is, $\Pi_{ij} \neq \Pi_{ji}$). Such an approach reduces the number of arrays shared among parallel processes. As the term in square brackets in equation (1) is antisymmetric under the interchange of particles i and j, momentum conservation is maintained.

The rate of change of the specific internal energy due to AV is

$$\frac{du_i}{dt}_{\mathrm{AV}} = \sum_j \frac{\Pi_{ij}}{2} m_j(\mathbf{v_i} - \mathbf{v_j})\cdot\nabla_i W_{ij}(h_i), \tag{5}$$

which guarantees conservation of entropy in the absence of shocks. It is straightforward to show total energy is conserved by our AV treatment: $\sum_i m_i(\mathbf{v}_i\cdot\dot{\mathbf{v}}_{\mathrm{AV},i} + du_i/dt_{\mathrm{AV}}) = 0$.

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