

Cycle 1

P1 = Compute Hydro Variable Slopes

P2 = Advect Hydro Variables to $\frac{\Delta t}{4}$

$$u_i^* = u_i^n - \frac{\Delta t}{4\Delta x} (F_{R,i}^n - F_{L,i}^n)$$

$$P3 = 4 \rho_i^{n+\frac{1}{4}} \frac{(u_i^{n+\frac{1}{4},k} - u_i^*)}{\Delta t} = \frac{1}{2} \left[\frac{\sigma_{\pm}}{c} (F - \frac{4}{3} E u) \right]_{i+\frac{1}{2}}^n \left. \vphantom{\frac{1}{2} \left[\frac{\sigma_{\pm}}{c} (F - \frac{4}{3} E u) \right]_{i+\frac{1}{2}}^n} \right\}^{n+\frac{1}{8}} + \frac{1}{2} \left[\frac{\sigma_{\pm}}{c} (F - \frac{4}{3} E u) \right]_{i+\frac{1}{2}}^{n+\frac{1}{4},k}$$

$$P4 = \frac{4}{\Delta t} (E_r^{n+\frac{1}{4},k+1} - E_r^n) = -\frac{1}{2} \left(\frac{\partial F_r}{\partial x} \Big|^{n+\frac{1}{4},k+1} + \frac{\partial F_r}{\partial x} \Big|_n \right)$$

$$+ \frac{\sigma_a c}{2} \left[a(T^{n+\frac{1}{4},k+1})^4 - E_r^{n+\frac{1}{4},k+1} \right]$$

$$+ \frac{\sigma_a c}{2} \left[a(T^n)^4 - E_r^n \right]$$

$$- \left[\frac{\sigma_{\pm}}{c} (F - \frac{4}{3} E u) u \right]_{i+\frac{1}{2}}^{n+\frac{1}{8},k}$$



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$$\frac{1}{c^2} \left(F_r^{n+\frac{1}{4}} - F_r^n \right) + \left[\frac{1}{3} \frac{\partial E_r^{n+\frac{1}{4}, k+1}}{\partial x} + \frac{1}{3} \frac{\partial E_r^n}{\partial x} \right] \frac{1}{2}$$

$$+ \frac{\sigma_r^{n+\frac{1}{4}}}{2c} \left(F^{n+\frac{1}{4}, k+1} - \frac{4}{3} E_r^{n+\frac{1}{4}, k} \right) + \frac{\sigma_r^n}{2c} \left(F^n - \frac{4}{3} E_r^n \right)$$

$$\frac{1}{c^2} \left(E^{n+\frac{1}{4}, k+1} - E^n \right) = - \frac{\sigma_a^{n+\frac{1}{4}} c}{2} \left[a(T^{n+\frac{1}{4}, k+1}) - E_r^{n+\frac{1}{4}, k+1} \right]$$

$$- \frac{\sigma_a^n c}{2} \left[a(T^n) - E_r^n \right] + \left[\frac{\sigma_r}{c} \left(F - \frac{4}{3} E_r \right) v \right]^{n+\frac{1}{8}, k}$$



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Cycle 1

C1: Advection Hydro Variables

$$u_i^{xx} = u_i^n - \frac{\Delta t}{2\Delta x} (F_{i+\frac{1}{2}}^{n+\frac{1}{2}} - F_{i-\frac{1}{2}}^{n+\frac{1}{2}})$$

C2: Update Momentum deposition

$$\frac{2\rho_i^{n+\frac{1}{2}} (u_i^{n+\frac{1}{2}, k+1} - u_i^{xx})}{\Delta t} = \frac{\sigma_E}{c} (F - \frac{4}{3} E u)_{i+\frac{1}{2}}^{n+\frac{1}{2}, k}$$

$$C3: \frac{2}{\Delta t} (E_r^{n+\frac{1}{2}, k+1} - E_r^n) = -\frac{1}{2} \left(\frac{\partial F_r^{n+\frac{1}{2}, k+1}}{\partial x} + \frac{\partial F_r^n}{\partial x} \right)$$

$$+ \left[\sigma_0 c (a T - E_r) \right]^{n+\frac{1}{2}, k+1} - \left[\frac{\sigma_E}{c} (F - \frac{4}{3} E u) u \right]^{n+\frac{1}{2}, k}$$

$$\frac{2}{c^2} \frac{(F_r^{n+\frac{1}{2}, k+1} - F_r^n)}{\Delta t} + \frac{1}{3} \frac{\partial E_r^{n+\frac{1}{2}, k+1}}{\partial x} +$$

$$\left[\frac{\sigma_E}{c} (F - \frac{4}{3} E u) \right]^{n+\frac{1}{2}, k} = 0$$



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$$\frac{2}{\Delta t} \left(E^{n+\frac{1}{2}, k+1} - E^{**} \right) = -\sigma_a C \left(a T^+ - E_r \right)^{n+\frac{1}{2}, k+1}$$

$$+ \left(\frac{\sigma_+}{c} \left(F - \frac{4}{3} E u \right) u \right)^{n+\frac{1}{2}, k}$$



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Cycle 2

Predictor = just like Cycle 1 predictor
except $n \rightarrow n + \frac{1}{2}$

C1: Advection Hydro Variables

$$u_i^{xx} - u_i^{n+\frac{1}{2}} \frac{\Delta t}{2\Delta x} (F_{i+\frac{1}{2}}^{n+\frac{3}{4}} - F_{i-\frac{1}{2}}^{n+\frac{3}{4}})$$

C2: Update Momentum Deposition

$$2\rho_i^{n+1} (u_i^{n+1,k+1} - u_i^{xx}) = \left[\frac{\sigma_{\pm}}{c} (F - \frac{4}{3} E u) \right]^{n+\frac{3}{4},k}$$

$$C3: \frac{E_r^{n+1,k+1} - E_r^n}{\Delta t} = -\frac{1}{3} \left(\frac{\partial F_r^{n+1,k+1}}{\partial x} + \frac{\partial F_r^{n+\frac{1}{2}}}{\partial x} + \frac{\partial F_r^n}{\partial x} \right)$$

$$\frac{2}{3} \left[\sigma_{ac} (a T^4 - E_r) \right]^{n+\frac{1}{4}} + \frac{1}{3} \left[\sigma_{ac} (a T^{n+1,k+1})^4 - E_r^{n+1,k+1} \right]$$

$$- \left[\frac{\sigma_{\pm}}{c} (F - \frac{4}{3} E u) u \right]^{n+\frac{1}{4}} - \left[\frac{\sigma_{\pm}}{c} (F - \frac{4}{3} E u) u \right]^{n+\frac{3}{4}}$$



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$$\frac{2}{c^2} \left(\frac{F_r^{n+1,k+1} - F_r^n}{\Delta t} \right) + \frac{1}{9} \left(\frac{\partial E_r^{n+1,k+1}}{\partial x} + \frac{\partial E_r^{n+1,k}}{\partial x} + \frac{\partial E_r^n}{\partial x} \right) =$$

$$-\frac{2}{3} \left[\frac{\sigma_t}{c} \left(F - \frac{4}{3} E u \right) \right]^{n+\frac{1}{4}} - \frac{1}{3} \left[\frac{\sigma_t^{n+1,k}}{c} \left(F^{n+1,k+1} - \frac{4}{3} E_u^k \right) \right]$$

$$\frac{E_r^{n+1,k+1} - E_r^n}{\Delta t} = -\frac{2}{3} \left[\sigma_{ac} (a T^4 - E_r) \right]^{n+\frac{1}{4}}$$

$$-\frac{1}{3} \sigma_{ac}^{n+1,k} \left(a \left(T^{n+1,k+1} \right)^4 - E_r^{n+1,k+1} \right)$$

$$-\frac{2}{3} \left[\frac{\sigma_t}{c} \left(F - \frac{4}{3} E u \right) u \right]^{n+\frac{1}{4}} - \frac{1}{3} \left[\frac{\sigma_t}{c} \left(F - \frac{4}{3} E u \right) u \right]^{n+1,k}$$



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