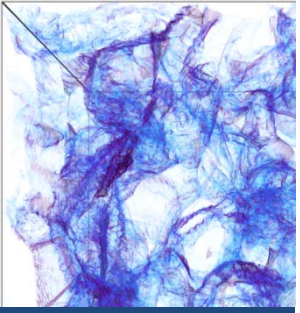

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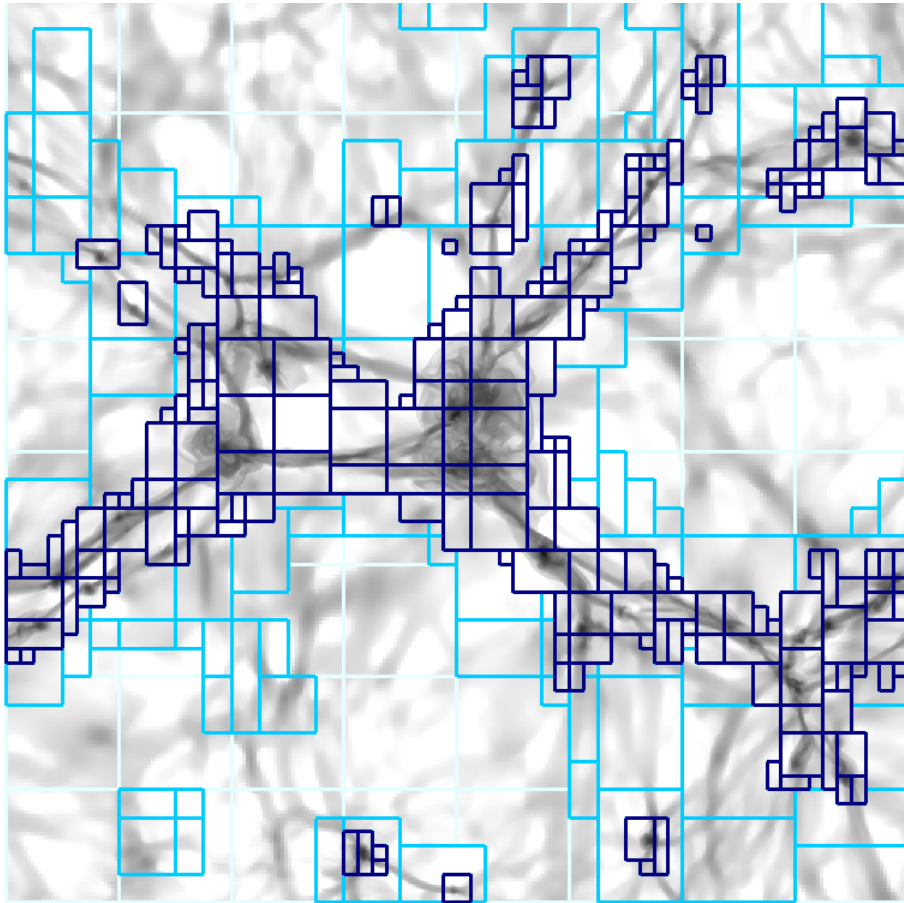
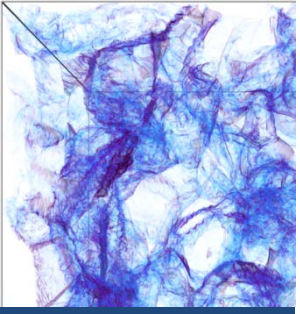
Adaptively Refined LES

Adaptive Mesh Refinement

- Adaptive methods are inevitable for many astrophysical applications: **clumping** of self-gravitating gas
- Two operations:
  - **Grid refinement** (interpolation)
  - **Projection** to coarser grids (averaging)
- Refinement criteria:
  - By overdensity
  - By vorticity, etc.





Adaptively Refined LES

- **Shear-improved model** (Lévêque et al. 2007): **Kalman filter** (Cahuzac et al. 2010) to separate mean flow and turbulent velocity fluctuations

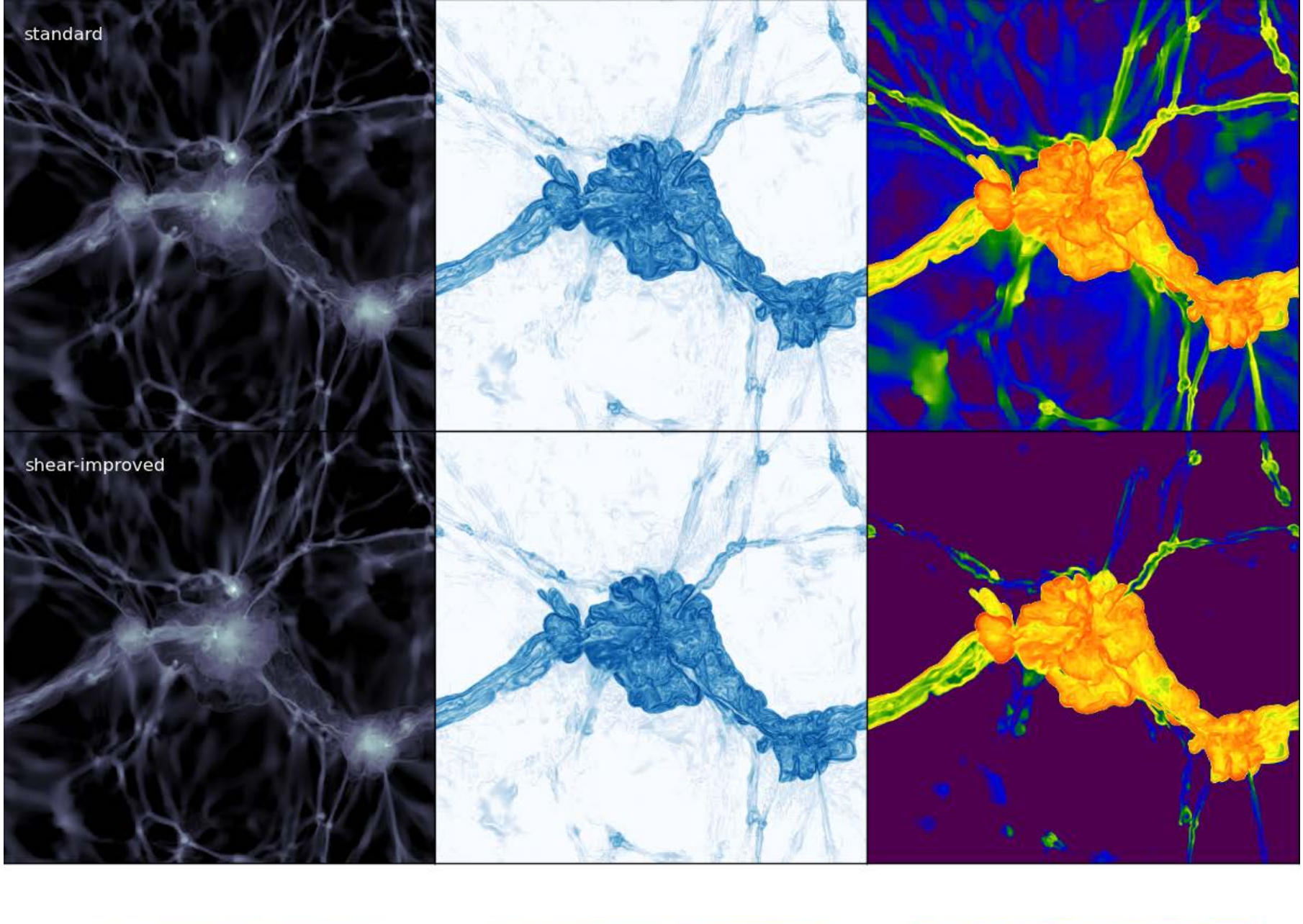
$$\mathbf{U} = \left[\mathbf{U}\right] + \mathbf{U}'$$

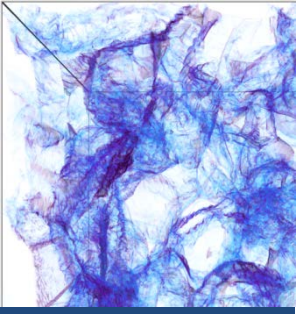
- **Eddy-viscosity** and **non-linear closures** for compressible turbulence (WS & Federrath 2011)

$$\tau_{ik} = 2C_1\Delta\rho(2K)^{1/2}\left[\frac{1}{2}\left(U'_{i,k} + U'_{k,i}\right) - \frac{1}{3}\delta_{ik}U'_{l,l}\right] - \frac{2}{3}\rho K\delta_{ik}$$

- AMR: **Compensation** of resolved kinetic energy difference by **subgrid scale energy**

$$\frac{1}{2\rho_{\mathrm{crs}}}\left(\rho U\right)^2_{\mathrm{crs}} + \left(\rho K\right)_{\mathrm{crs}} = \sum_n \frac{1}{2}\rho_n U_n^2 + \sum_n \left(\rho K\right)_n$$


standard
shear-improved
10^9 10^{10} 10^{11} 10^{12} 10^{13}
$\rho\,[M_\odot/\mathrm{Mpc}^3]$
10^1 10^2 10^3 10^4
$\omega\,[(\mathrm{km/Mpc})/\mathrm{s}]$
10^{-2} 10^{-1} 10^0 10^1 10^2 10^3 10^4 10^5
$K\,[(\mathrm{km/s})^2]$



Magnetic Field in the ICM

- **Turbulent velocity dispersion**: $\sigma^2_{\rm turb} = (U')^2 + K$
- Estimate of the magnetic field in the saturate regime: $B^2 / (8\pi) \simeq 0.2 \rho \sigma^2_{\rm turb}$ (e.g. Ryu et al. `08)