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

\[ U = [U] + U' \]

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

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

• AMR: Compensation of resolved kinetic energy difference by subgrid scale energy

\[
\frac{1}{2\rho_{crs}} (\rho U)^2_{crs} + (\rho K)_{crs} = \sum_n \frac{1}{2} \rho_n U_n^2 + \sum_n (\rho K)_n
\]
The Santa Barbara Cluster with Shear-Improved SGS Model
**Magnetic Field in the ICM**

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