# Exercises — 9

## Analytical Exercise:

Transform the momentum and energy equations in Eulerian form and into Lagrangian form

## Numerical Exercise: Analysing the gas content of a simulated galaxy at z=0.8

1. Which fraction of all, cold and hot gas in the halo is residing in the galaxy (assume a T-cut of 10.000K to distinguish cold/hot gas)?

2.a How does the 3D gas particle distribution within 1/10 $r_{vir}$ along the 3 major axes look like (3 different projections)? Color-code particles by T!

2.b Rotate the system around the z-axis with an angle of 52 degrees, how does the 3D gas particle distribution change (plot again 3 different projections within 1/10 $r_{vir}$)? Color-code part. by T!

3.a Plot the smoothing length vs rho (convert rho in particles/ccm)

3.b Plot the phase diagram rho [particle/ccm] vs T [K].

4. Plot the 2D gas surface density profiles ($\log(\Sigma_{gas})$ [$M_\odot/pc^2$]) out to the virial radius

Give a brief interpretation for all results!

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## Information for computational exercise: Cosmological hydrodynamic zoom-in simulation of a massive halo at z=0.8

- Run with a modified version of Gadget-3 (SPHGal, modern SPH!), for details see *Choi+17, Hirschmann+17*
- WMAP3 cosmology, IC details described in *Oser+10, Hirschmann+12* (Halo 215)
- At z=0.8: $M_{halo}$= 3.9e12 $M_{\odot}$/h and $R_{vir}$= 195 kpc/h
- gravitational softening DM: 800pc; gravitational softening gas/stars: 400pc

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Helpful instructions for numerical exercise:

- Content of the ascii-file: masses, positions and smoothing length of individual **gas** particles (but sim. run with DM, stars and BHs)

**particlemass, pos_x, pos_y, pos_z, hsml (smoothing length), rho, temp, sf_rate**

- Code units of masses: $10^{10}$ $M_\odot/h$; positions (physical): kpc/h; temperature: K; density (physical): $(10^{10}\ M_\odot/h)/(kpc/h)^3$
- Note that (for your convenience!) the positions of the gas particles in the ascii-file are already centred, and rotated along the major axis ("principal axis transformation")
- The galaxy is typically defined as the gas/stellar mass within **1/10 of $R_{vir}$**, i.e. when calculating the gas mass within the galaxy, consider particles within that sphere of $0.1*R_{vir}$
- For converting rho (code units) in units of particles/ccm, for simplicity assume that the gas is composed of hydrogen (i.e. proton mass)
- For 2D projection, take the projection along the z-axis
- 2D surface density profiles means surface density vs radial distance (i.e. you have to bin the gas particles in radial annuli)

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- Reading suggestions: Not part of the exam!
  - Dolag+08: review article on both SPH and grid codes
  - Springel+10: "Smoothed Particle Hydrodynamics in Astrophysics". excellent review article on SPH
  - Tessier+15: "Grid-Based Hydrodynamics in Astrophysical Fluid Flows", excellent review article
  - Springel+10: "E pur si muove: Galilean-invariant cosmological hydrodynamical simulations on a moving mesh", description of the moving mesh Arepo code