The gas cosmological power spectrum in RAMSES

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The cosmological power spectrum

- Measure of the density field on different scales: characteristic of LCDM
- Fourier transform of the density field on a uniform grid
- Map simulation output onto a regular grid (for dark matter and **gas**)
- Dark matter particles, gas properties on grid cells

Importance of initial resolution (ICs):

- **Experiment:** Run simulation with different resolution in the ICs (initial resolution) but set simulation to resolve in the same final resolution (max level)

- We can set the maximum refinement level to fix the force resolution, minimum gas mass etc.

RAMSES (Teyssier 2002)

Adaptive mesh refinement (AMR) code:

- Forces calculated on a grid
- Refines grid in high density regions
- Refines to maintain physical resolution

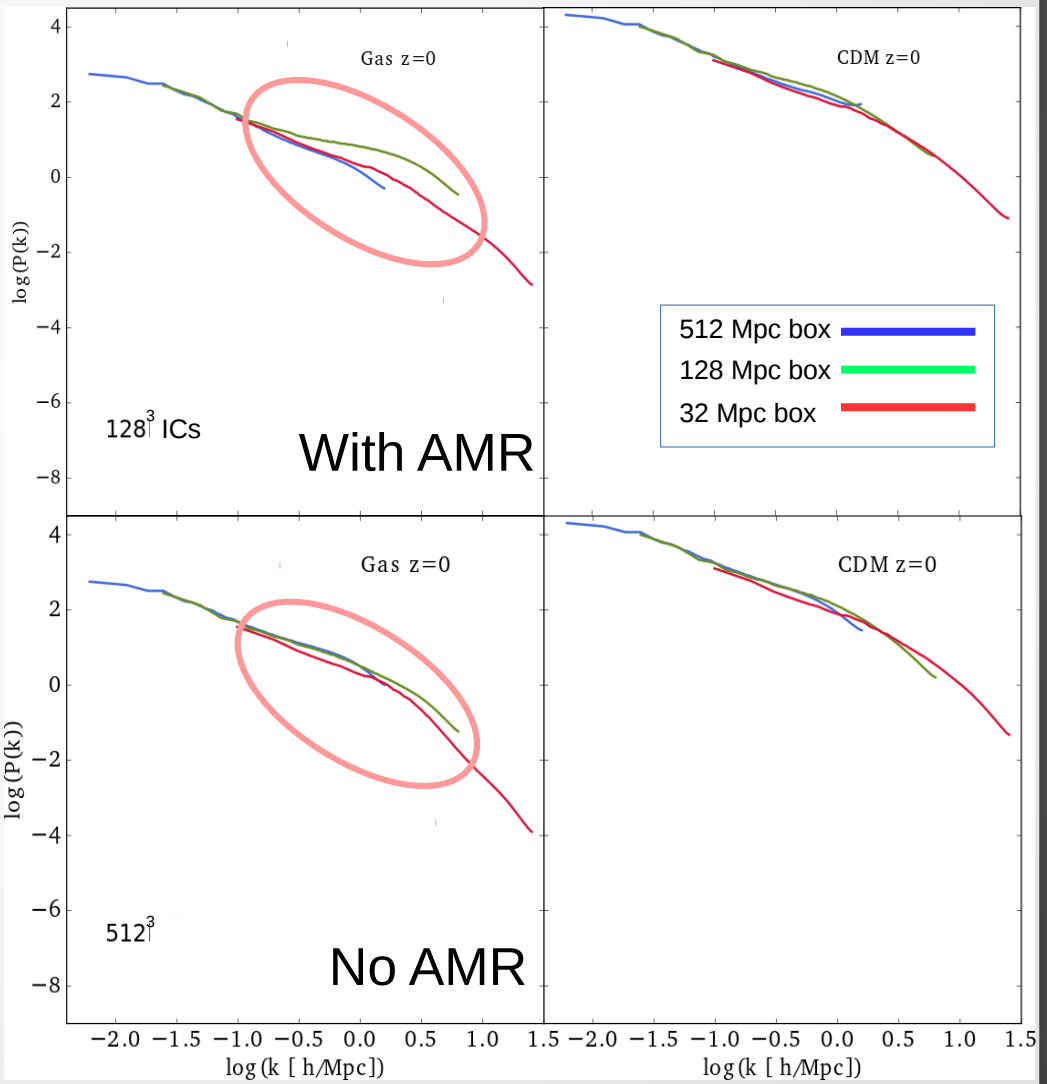
- Refinement strategy: when the number of particles in a cell exceeds a threshold or to maintain the spatial resolution.

Simulations

- 4 difference coarse grids:
    - 2^6, 2^7, 2^8 and 2^9
- 3 different simulation volumes:
    - 512 Mpc, 128 Mpc, 32 Mpc on the side
- Set the same highest resolution grid (2^9) in each case
- Use different simulation boxes to probe different scales

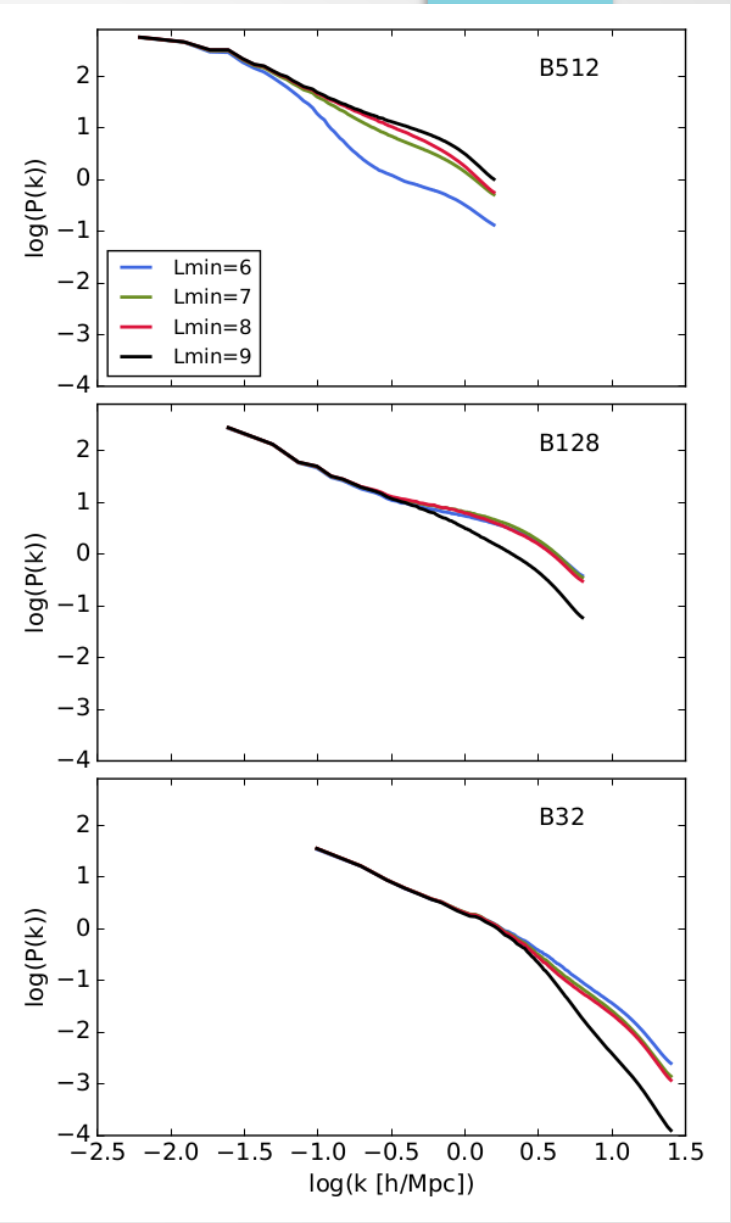
Results

- For the dark matter:
  - Good match across simulations
  - Similar results at different resolutions
- For the gas:
  - Low resolution shows excess at low resolution
  - No-AMR case shows reasonable fit.



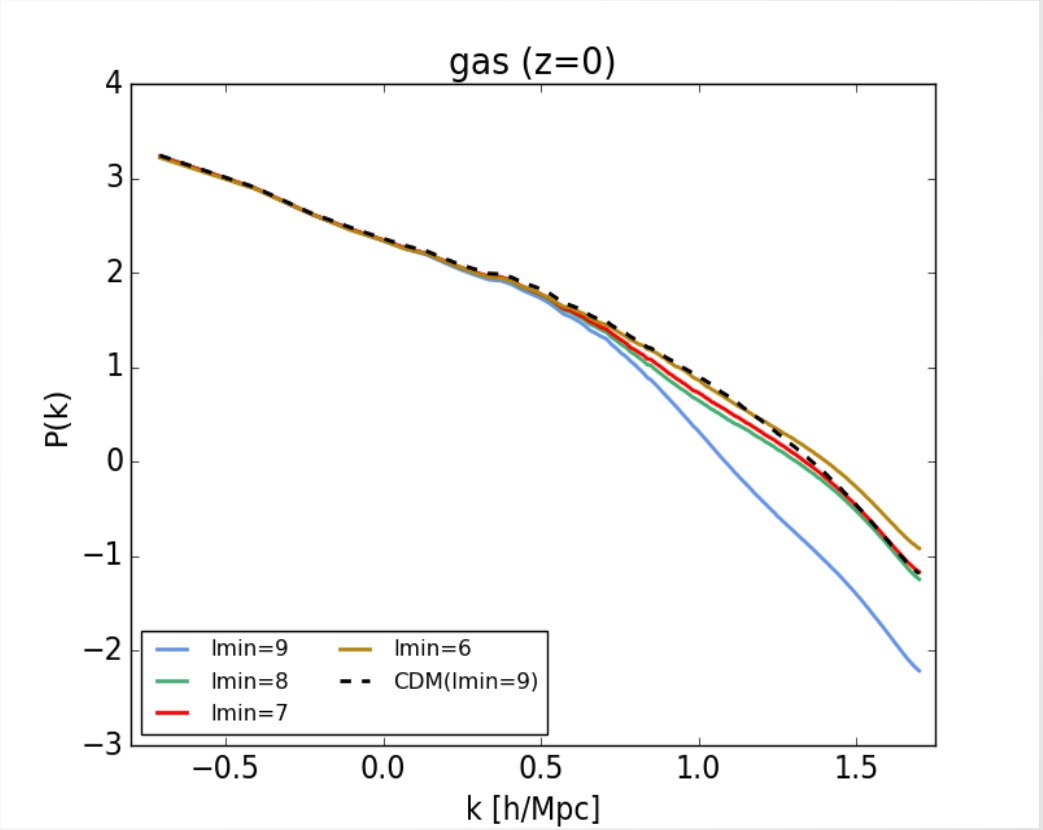
Results

- In the largest box increasing the IC resolution results in convergence towards the Lmin=9 (no-AMR) result
- On smaller scales there is a distinct separation between with and without AMR



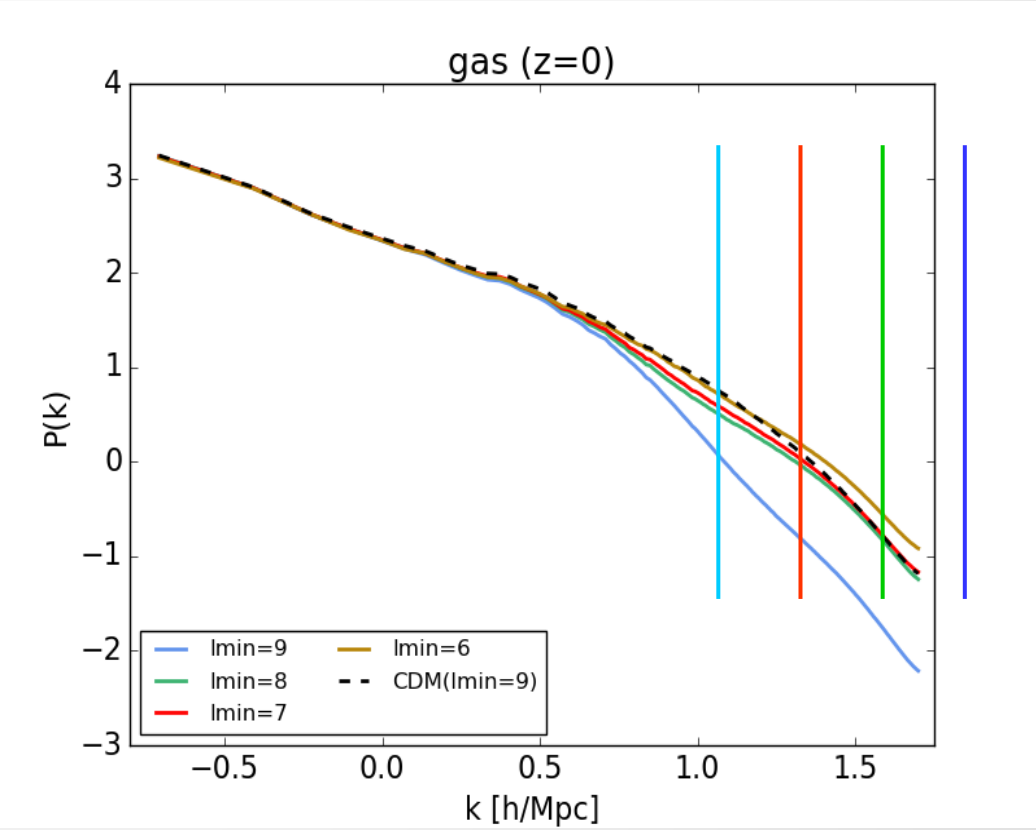
Results

- In the 128 and 32 Mpc box simulations:
  - Simulations with AMR have similar power spectra
  - Diverge from the no-AMR case by an order of magnitude
  - Gas matches DM with AMR



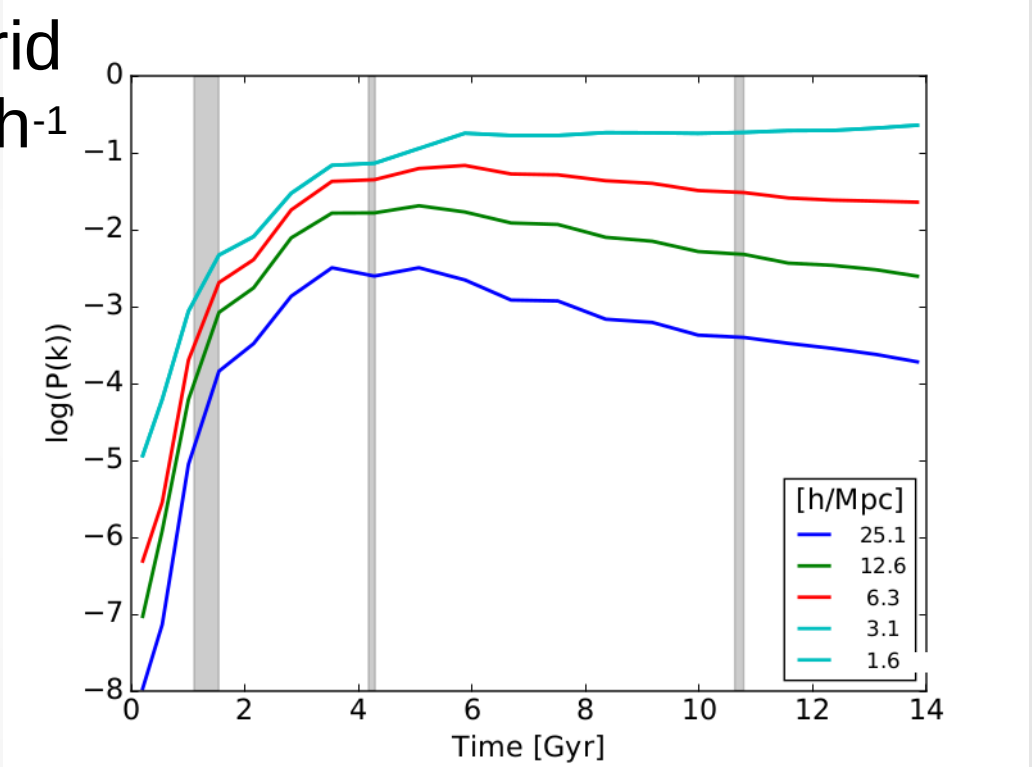
Results

- The system evolves through time, so when and the ICs are similar:
  - When does the difference appear?
- Select values of ‘k’ and follow through time



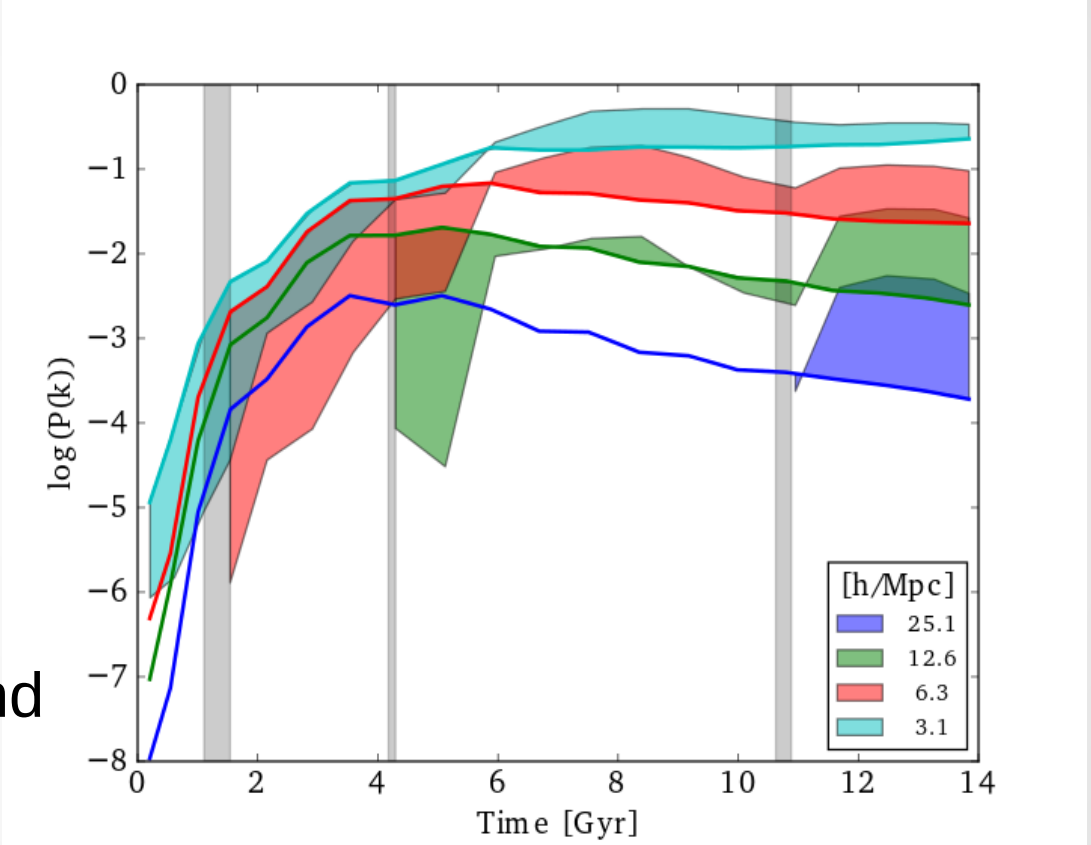
Results

- For the no-AMR (coarse grid = 2^9) simulation in the 32h^{-1} Mpc box
- Well behaved evolution at different ‘k’
- On smallest scales maximum power is at 4 Gyr



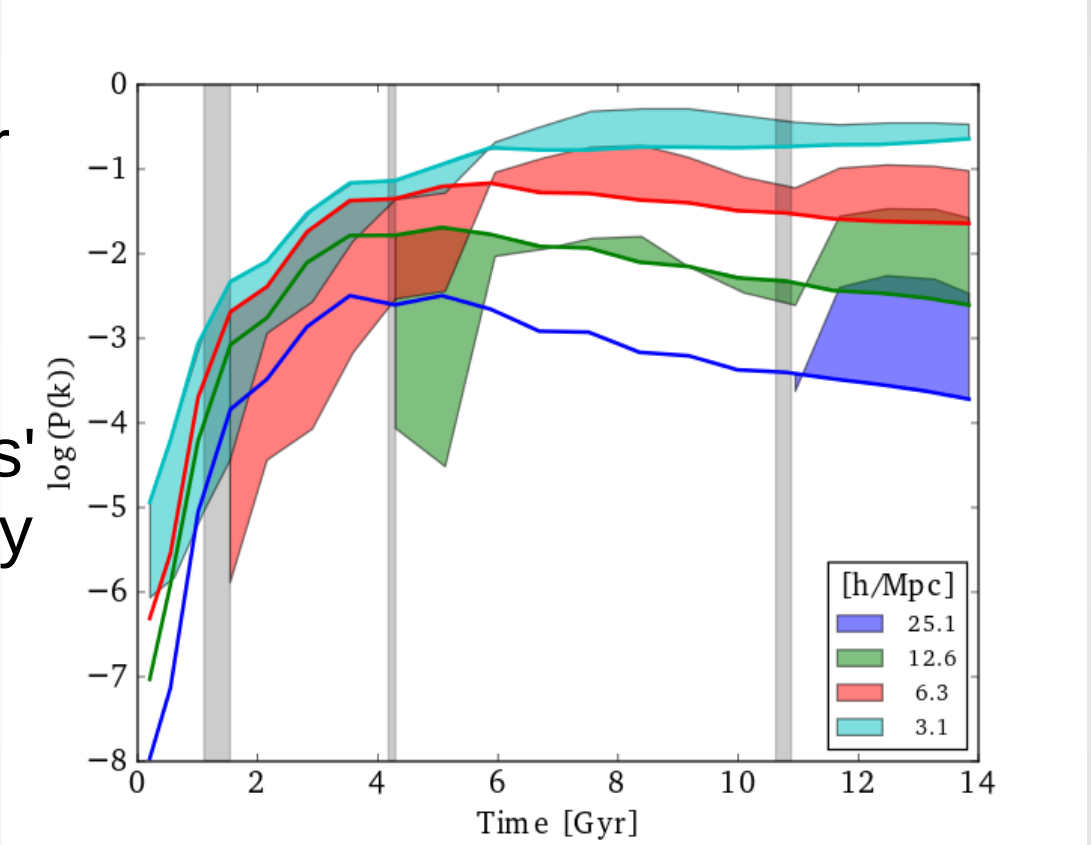
Results

- Compare the Lmax=6 with the no-AMR case
- Grey lines show when the global refinements occur
- Shaded region is the difference between AMR and non-AMR cases
- AMR case shown only when resolution reaches that level



Results

- Refinement strongly influences the gas power spectrum
- The last refinement 'kicks' the power spectrum away from the non-AMR case (green region).
- Second to last refinement takes 1-2 Gyr to kick gas, last refinement faster



Cause

- Refinement results in density increase
- Density = cooling?
- Without cooling difference disappears but small scale structures are absent
- Need feedback etc. to mitigate this
- Mapping AMR to regular grid might not be trivial

Conclusions

- Gas and dark matter power spectra are different in the non-AMR case for large ‘k’
- Similar in the AMR cases
- Gas sensitive to refinement strategy and/or cooling
- Sudden changes to the system with refinements