Dust Dynamics in Kelvin-Helmholtz Instabilities

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Simulating Dust in Space

MPI-AMRVAC

Study dust dynamics using numerical simulation:

MPI-AMRVAC

- Grid based parallel code
- Adaptive mesh-refinement
- Up to 3D Cartesian and curvilinear grids
- Several physics modules: HD, MHD, SR, HD+Dust,...
- Written in `fortran`

Info: Keppens et al., 2012

Get it now at `homes.esat.kuleuven.be/~keppens/`

HD multi-fluid dust module

- Dust as extra fluids
- Dust is pressureless gas
- Every dust species has a set grain size and grain density
- Gas-dust coupling using combined Epstein + Stokes drag law

Grain size distribution

Following simulations:

- All dust fluids have same grain density, i.e. silicate densities ($\rho = 3.3$ g cm^{-3})
- Different species represent different parts of the size distribution
- Typically canonical ISM size distribution ($n(a) \propto a^{-3.5}$)
- Grains radii a between 5nm and 250nm, each of the N dust fluids represents a part from $a_{min,i}$ to $a_{max,i}$, which are chosen by setting equal parts of the total dust mass in each dust fluid.
- Effective radius $\bar{a}_i$ is weighted by the drag force over the represented interval between $a_{min,i}$ and $a_{max,i}$

Dusty Kelvin-Helmholtz Instability

Kelvin-Helmholtz Instability

Classical KHI:

- Shear induced instability
- No density or pressure difference needed
- Most simple setup: discontinuity in velocity is unstable for all wavelengths
- Stabilization can be introduced by surface tension of a transition layer

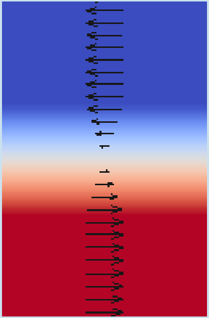
De Sterrennacht, Vincent van Gogh

Kelvin-Helmholtz Instability

Approach: We study the effect of dust on the KHI by comparing the analytical gas-only solution with gas+dust simulations.

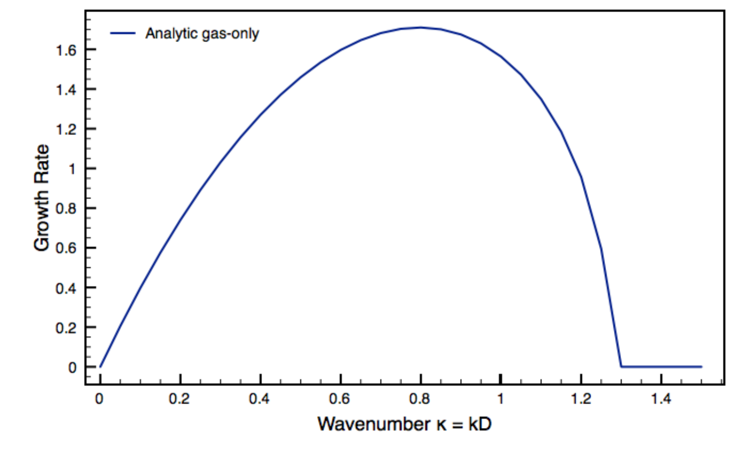
Setup:

- Stabilized configuration with two layers, separated by a thin layer.
- Uniform gas density.
- Effective resolution 1024×2048.
- Basic setup: 4 dust types, size distribution between 5nm and 250nm.
- Subsonic velocity difference.



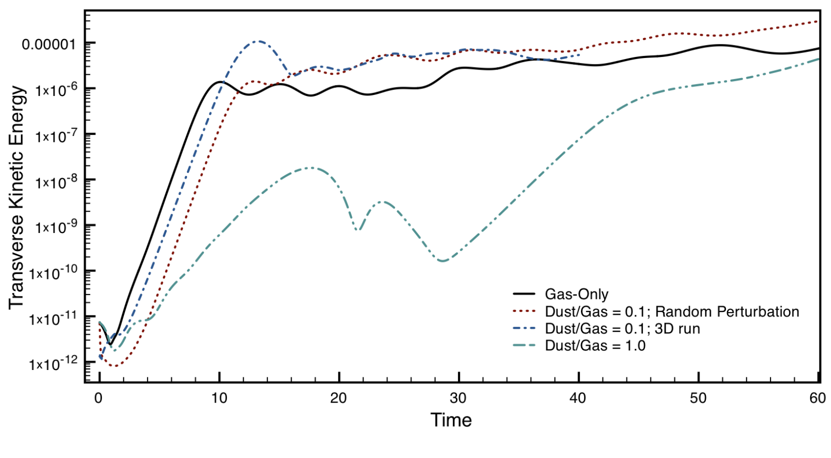
Linear phase

Solving the dispersion relation for gas-only:



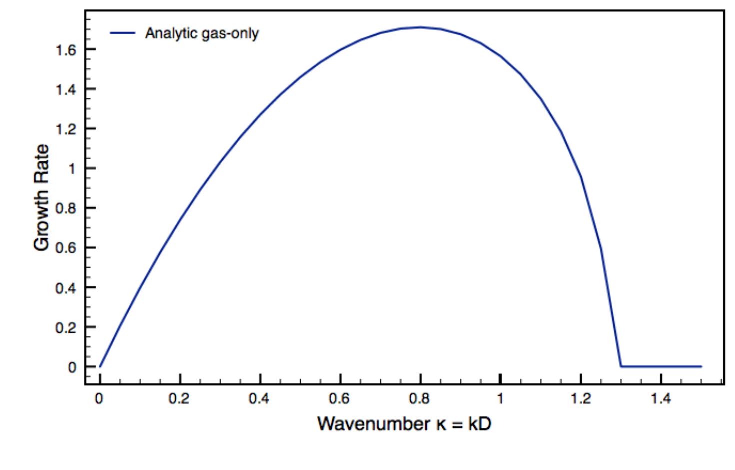
Linear phase

Gas linear phase growth known from solving the dispersion relation. Growth in the simulations can be inferred from the kinetic energy perpendicular to the flow:



Linear phase

From which we derive the dependency of the growth rate on the wavelength of the perturbation.



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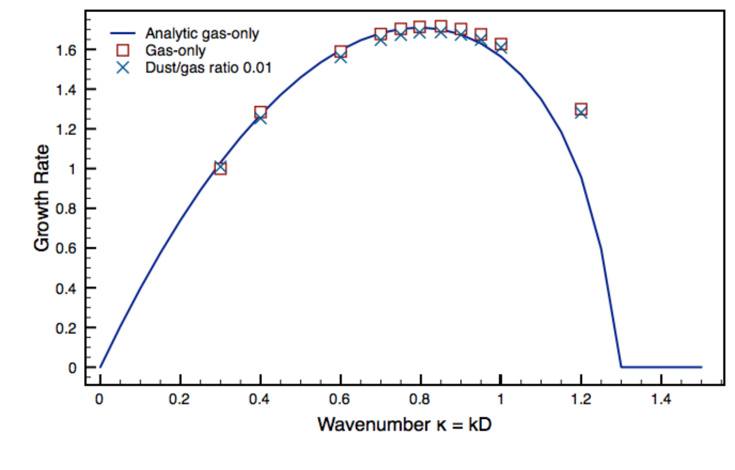

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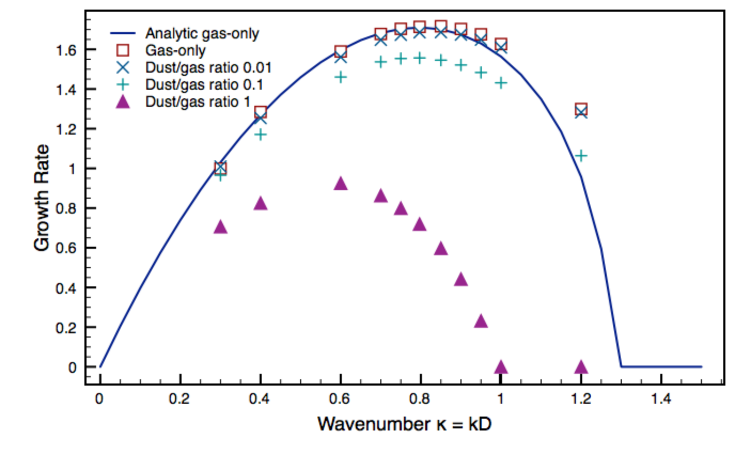
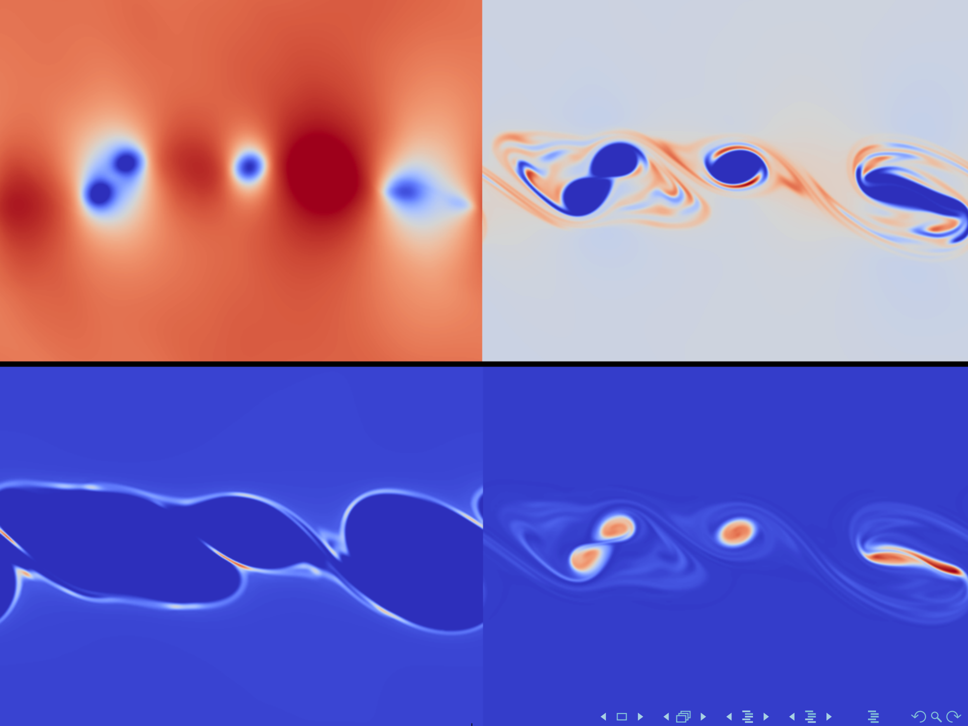


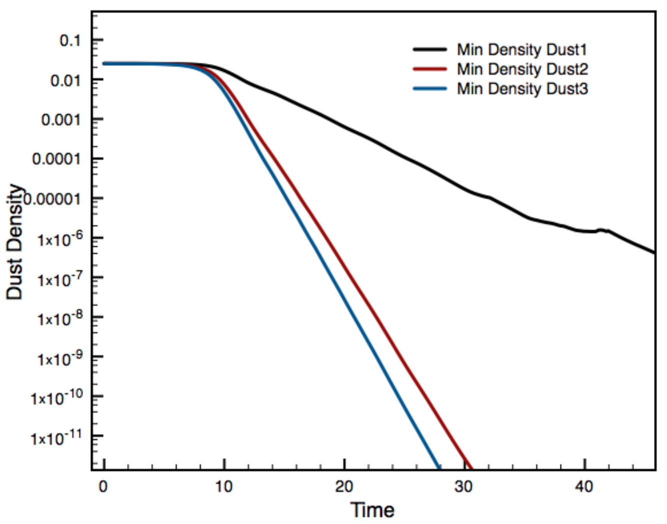
Kelvin-Helmholtz Instability

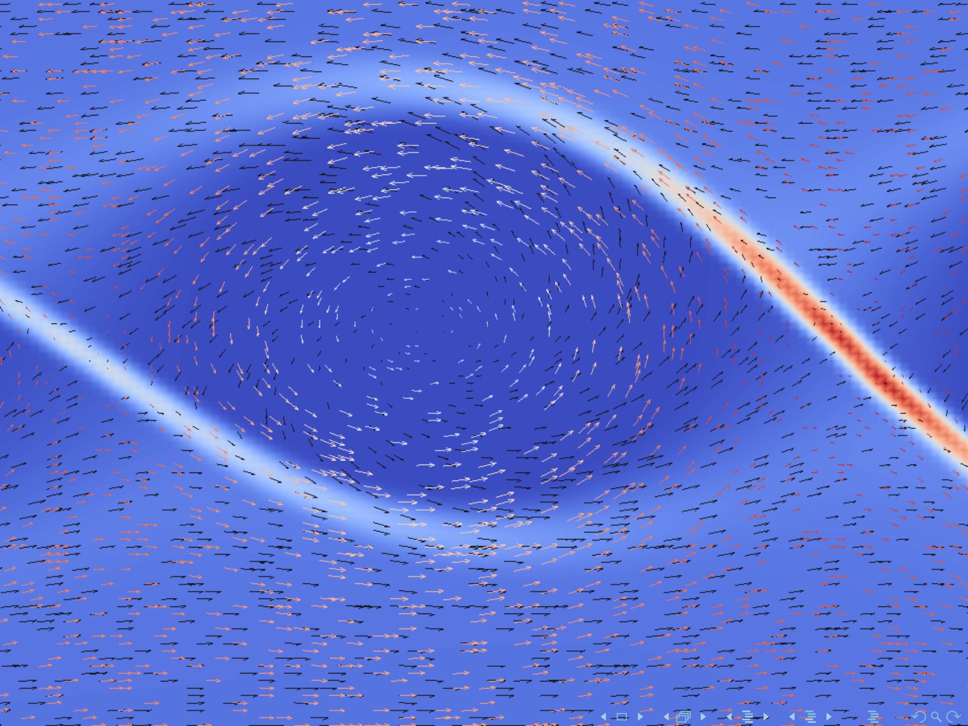
So, what does it look like?



Non-linear phase: The Dust Vacuum Cleaner

Exponential decrease in dust density from start of non-linear phase:





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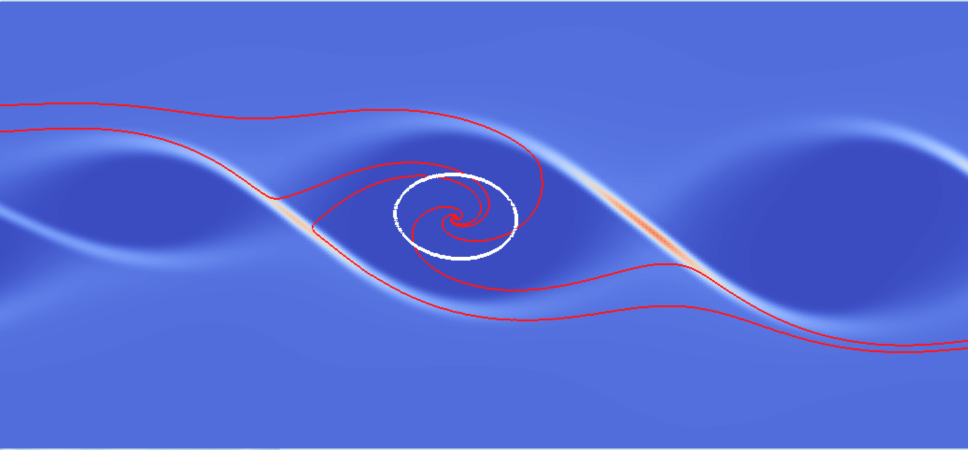
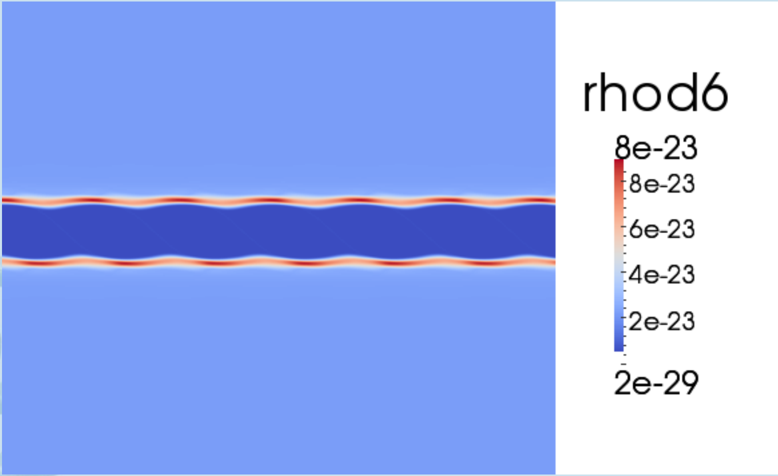


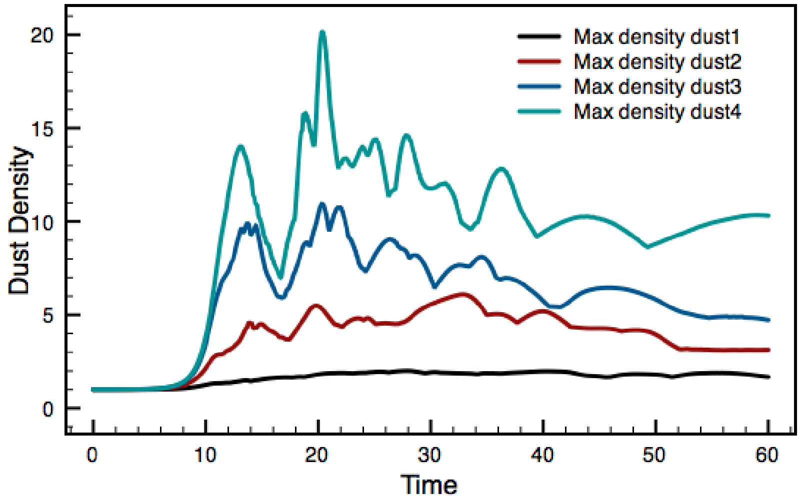
Non-linear phase

After initial linear KH-phase: dust separation phase.



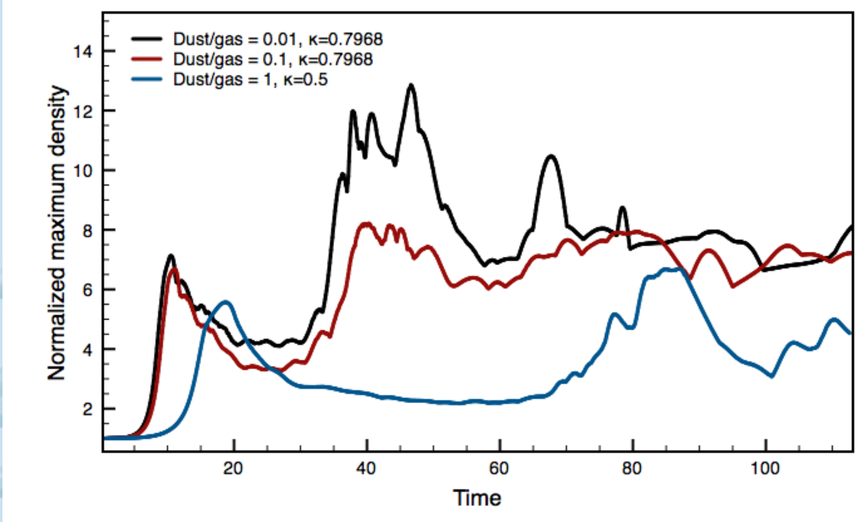
Non-linear phase: Dust Density Increase

Heavier dust species tend to clump to higher densities:



Non-linear phase: Dust Density Increase

Strength of clumping deceases with dust/gas ratio



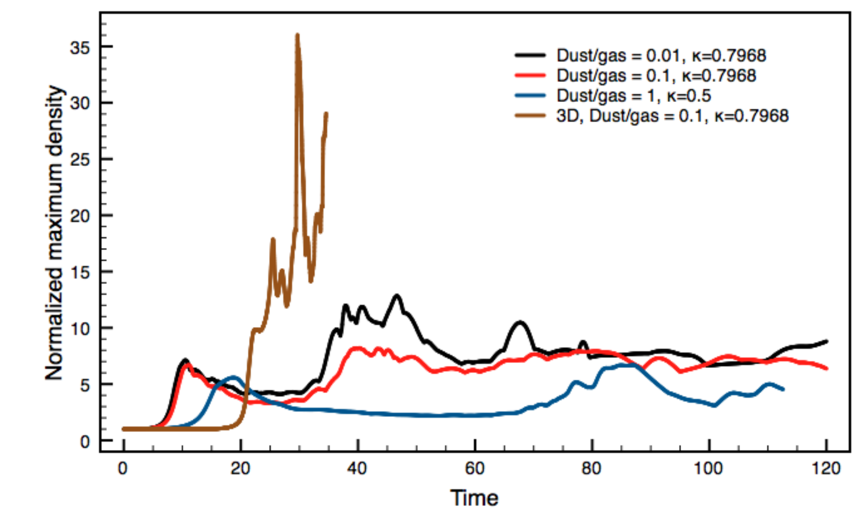
3D simulation

Setup:

- 2 dust species (between 5nm and 250nm)
- Uniform gas density
- Effective resolution $256\times1024\times256$
- Physical size $\sim (2\lambda)^3$
- Dust/Gas ratio 0.1
- $\kappa = k_x D = 0.7968$

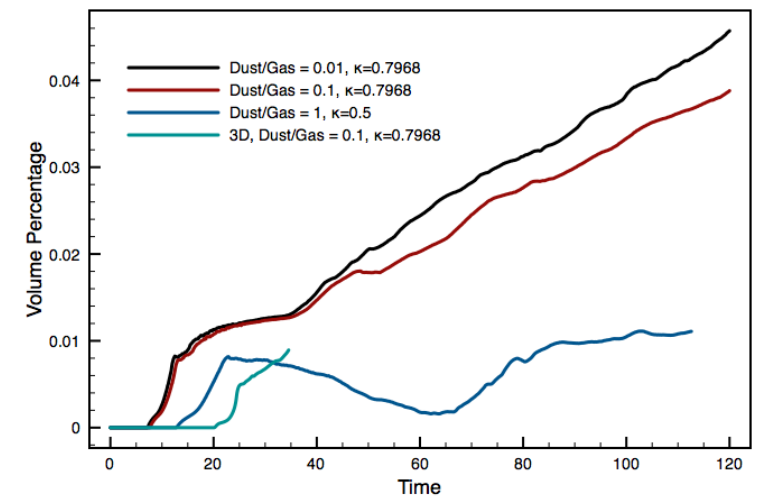
Non-linear phase: Dust Density Increase

Strength of clumping deceases with dust/gas ratio



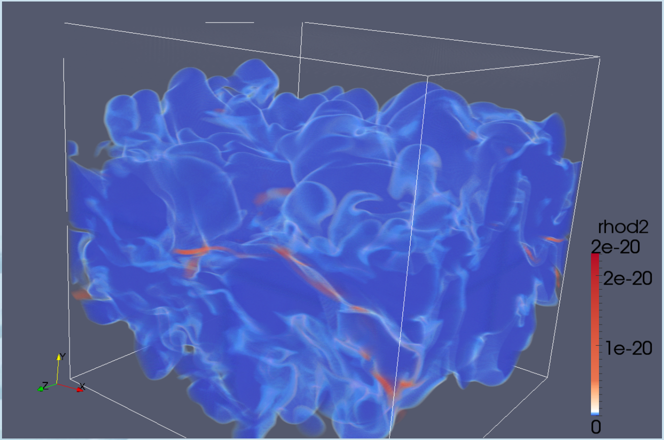
Non-linear phase: Dust Density Increase

Percentage of the volume where the dust increases a factor between 2.5 and 10:



Non-linear phase: Dust Density Increase

In 3D, enhanced dust densities end up in "filaments" along the vacuum bubbles:



Thank you for your attention, questions?