Dust Dynamics in Astrophysical Fluids

Tom Hendrix

Centrum voor Plasma-Astrofysica
K.U.Leuven

Brussels, 14 May 2012

Dust Dynamics in Astrophysical Fluids

Overview

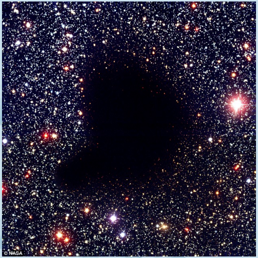
- Introduction: Dust in Space
- Simulating Dust in Space
- Dusty Kelvin-Helmholtz Instability
- Outlook

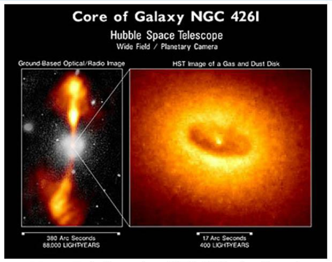
Dust in Space

Dust in Space

Dust plays an important role in a broad range of locations in space. E.g.:

- Torus around SMBHs
- Molecular clouds (e.g. stellar formation)
- Protoplanetary disks
- Cometary outflows





Left figure: Barnard 68, credit VLT,ESO. Right figure: NGC 4261 in radio and optical, credit NASA

Dust in Space

However, dust is (often) dilute, $n_d \approx 10^{-12}$ cm^{-3} in the ISM. Therefore, it has often been ignored in simulations. However, in the last decade several approached have been used to investigate the role of dust dynamics:

- Two-fluid Eulerian HD (Paardekooper & Mellema (2006); van Marle, Meliani and Keppens (2011))
- Two-fluid SPH (Laibe & Price (2011))
- Hybrid methods (Youdin & Johansen (2007), Miniati (2010))

Protoplanetary Disks

How can dust clump to protoplanets?

Dust dynamics is complex:

- Important 3D effects
- Large range of dust size: $\approx 10^{-9}$ m - 10 m
- Size distribution?
- Gas-dust drag law can vary significantly in different regions
- Multitude of timescales: Keplerian rotation, drag, infall, instability,...

Credit: NASA/ESA/L. Ricci (ESO)

E.g. Meheut et al. (2012), *Formation and long-term evolution of 3D vortices in protoplanetary discs*, using the MPI-AMRVAC code

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,...

Keppens et al., 2012

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 drag law

Dusty Kelvin-Helmholtz Instability

Kelvin-Helmholtz Instability

Classical KHI:

- Shear induced instability
- No density of 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

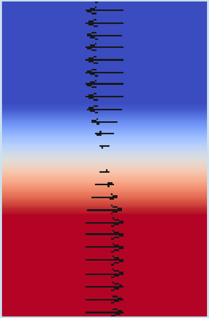
De Sterrennacht, Vincent van Gogh

Kelvin-Helmholtz Instability

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

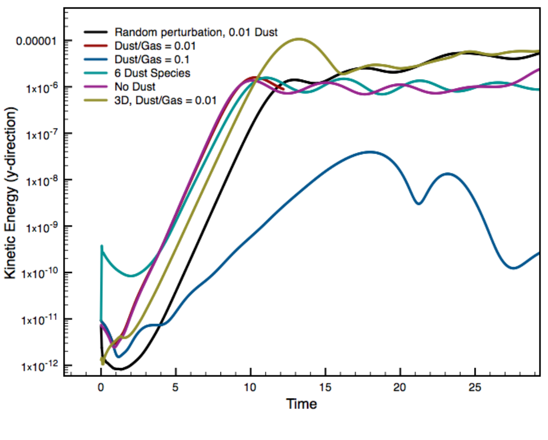
Setup:

- Stabilized configuration with two layers, separated by a thin layer.
- Uniform gas density.
- Different setups with only dust in one layer or uniform in both.
- Effective resolution 1024×2048.
- Basic setup: 4 dust types, size distribution between 5nm and 200nm.
- Subsonic velocity difference.



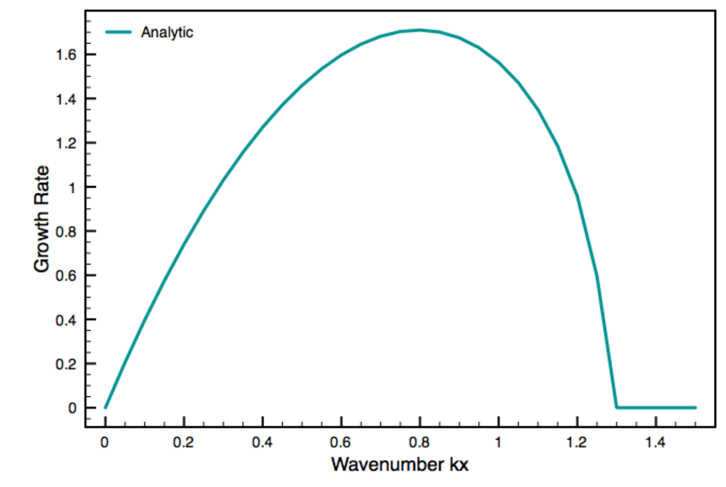
Linear phase

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:



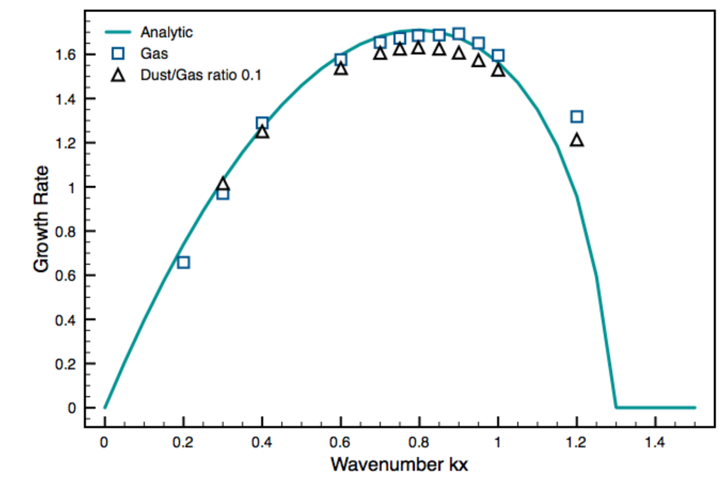
Linear phase

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



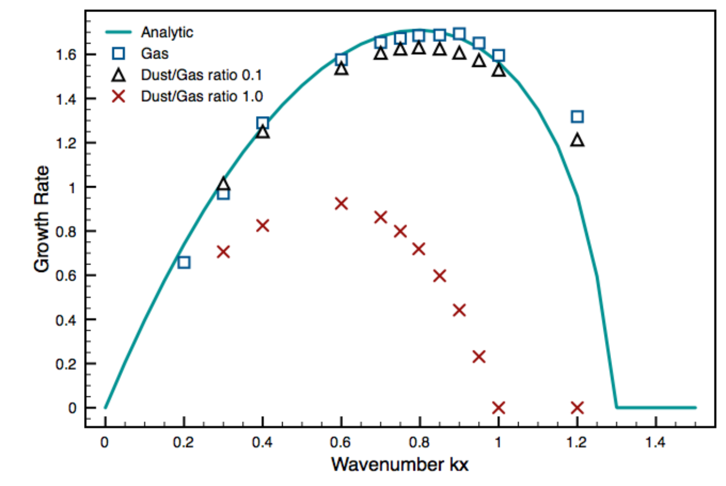
Linear phase

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



Linear phase

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

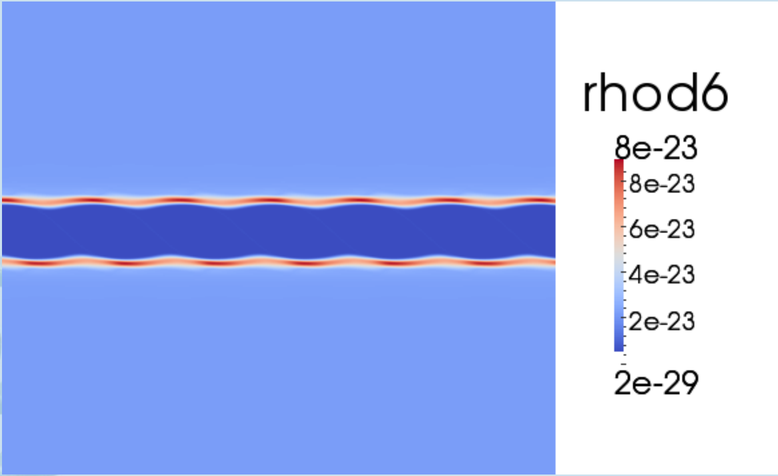


Kelvin-Helmholtz Instability

So, what does it look like?

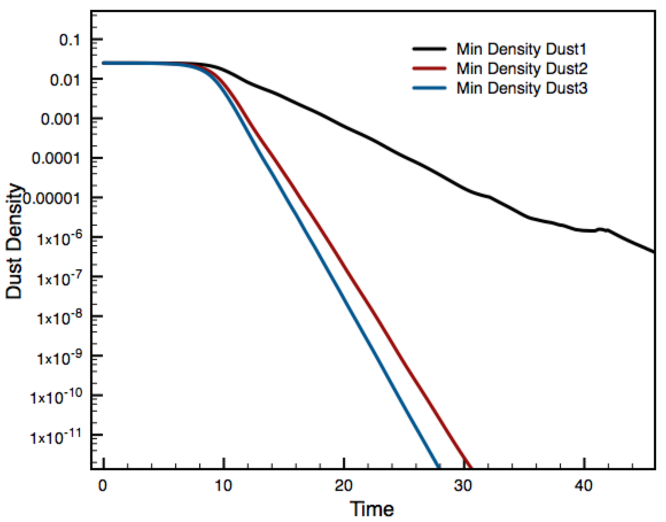
Non-linear phase

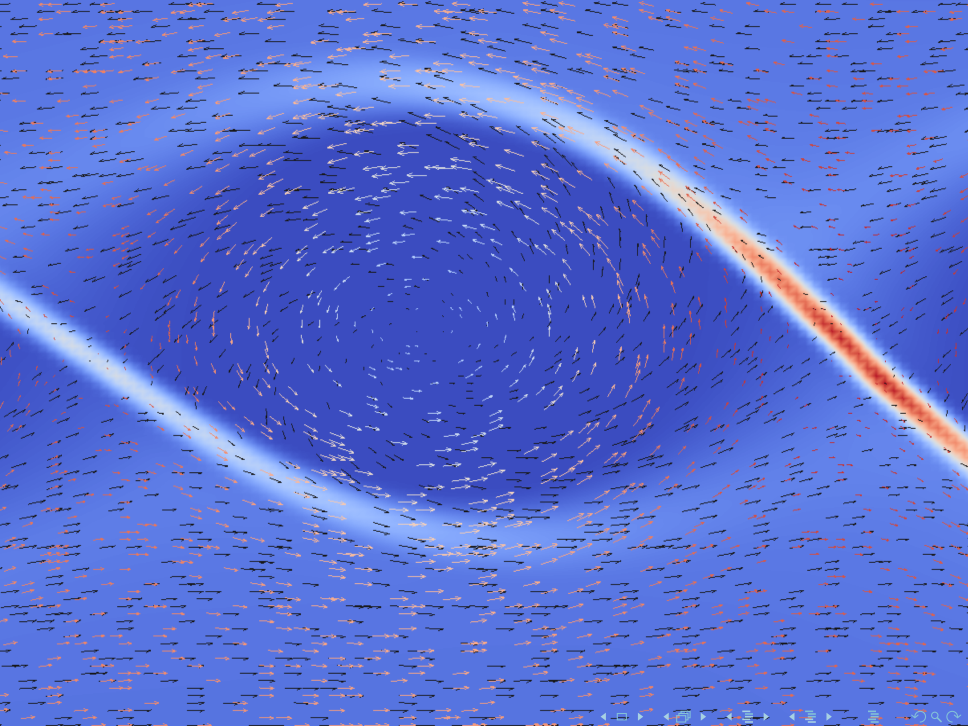
After initial linear KH-phase: dust separation phase.



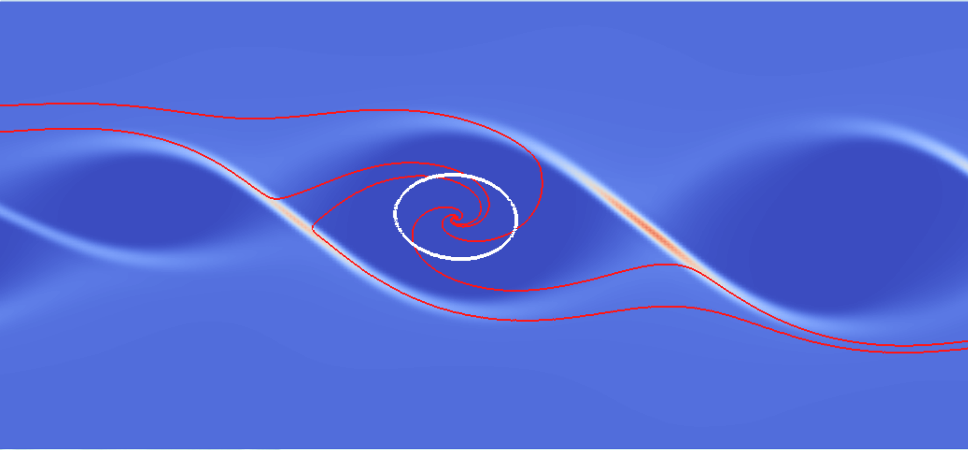
Non-linear phase: The Dust Vacuum Cleaner

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



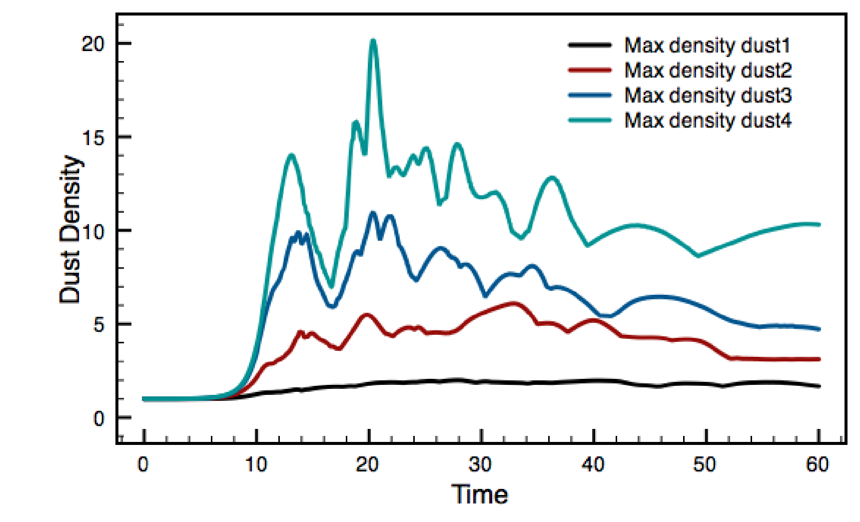


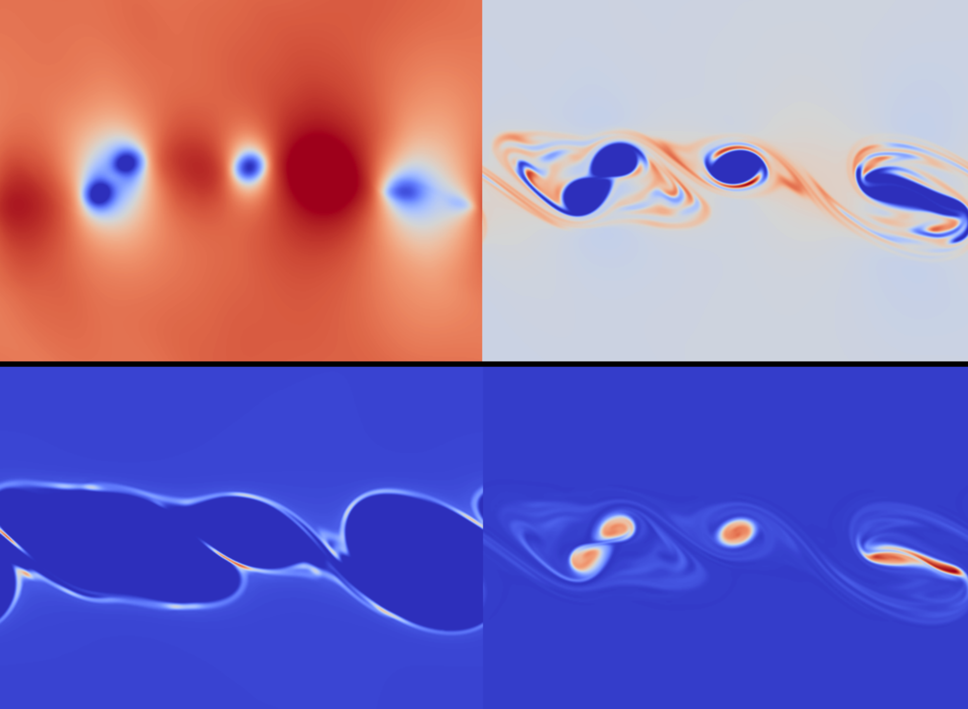
Non-linear phase: The Dust Vacuum Cleaner



Non-linear phase: Dust Density Increase

Heavier dust species tend to clump to higher densities:

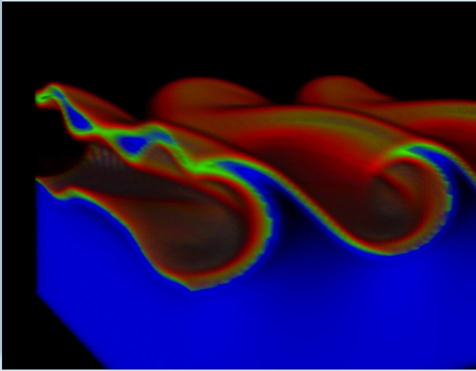




Outlook

Outlook

- Investigation of dust rarefaction/clumping in 3D
- Study dust in other astrophysical instabilities: Rayleigh-Taylor and Richtmyer-Meshkov
- Expansion of dust code to MHD
- Study dust in specific astrophysical setups such as the protoplanetary disk, etc.



Thank you for your attention, questions?