Linear and non-linear Multi-Species Streaming Instability

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Streaming Instability

Youdin & Goodman (2005) and Youdin & Johansen (2007)

Main assumptions:

- Shearing-box framework.
- No vertical stratification.
- One dust-species.

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- Dust-to-gas density ratio: $\epsilon = \dfrac{\rho_\mathrm{d}}{\rho_\mathrm{g}}$.

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- No vertical stratification.
- One dust-species.
- Constant background.
- Perturbations: $\delta f \sim e^{k_x x + k_z z - \omega t}$

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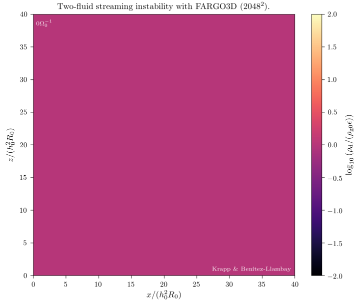
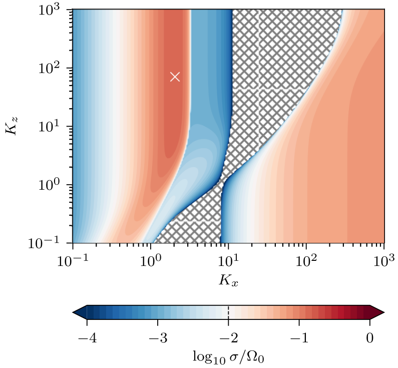
- Dust-to-gas density ratio: $\epsilon = \dfrac{\rho_\mathrm{d}}{\rho_\mathrm{g}}$.



FARGO3D simulation based on model BA from Johansen & Youdin (2007); Bai & Stone (2010).

Outcome of the Linear Theory

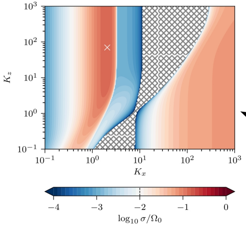
- Timescale for the instability to fully develop: $T \sim 1/\sigma$.
- Lengthscale of the fastest growing mode: $\lambda = 2\pi/k_{\max}$.

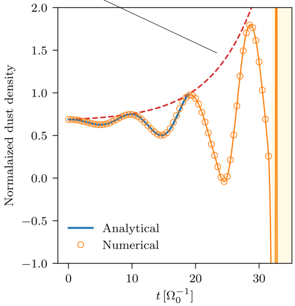


Stability map for the streaming instability with two dust-species.

Outcome of the Linear Theory

Solution of the eigenvalue problem used as initial condition for simulations.





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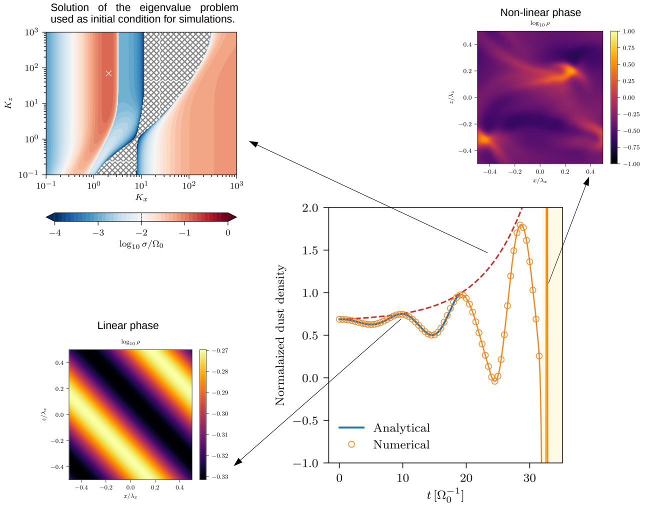
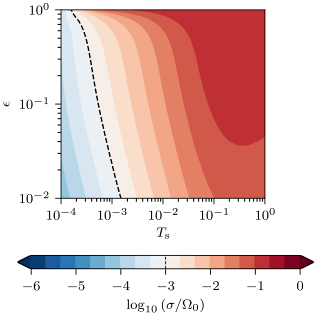


Analytical solution defines a controlled framework for numerical simulations.

The Two-Fluid Problem

Maximum growth rate as a function of the Stokes number and the dust-to-gas density ratio.



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- Lengthscale $\lambda \lesssim H$

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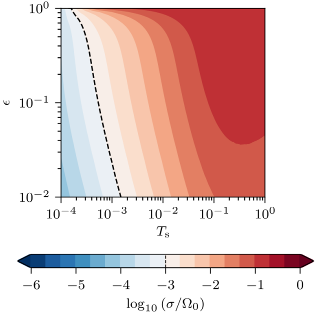

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How are T and λ modified when considering MORE than ONE dust species?

Multispecies Linear Phase

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https://doi.org/10.3847/2041-8213/ab2596

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Streaming Instability for Particle-size Distributions

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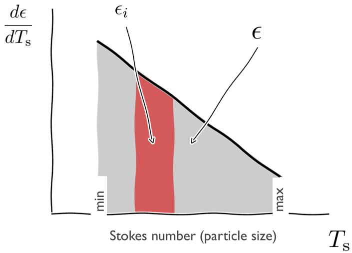


How many dust species do we need to consider to ensure convergence of the linear phase?

Example: Two distributions with the same mass, $\epsilon = 1$, but different $T_{\mathrm{s,max}}$.

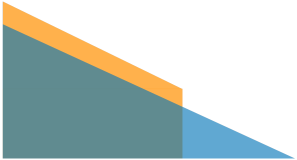
$\Delta T_{\mathrm{s}}^{\mathrm{I}} = \left[10^{-4}, 10^{-1}\right]$ $\Delta T_{\mathrm{s}}^{\mathrm{II}} = \left[10^{-4}, 1\right]$

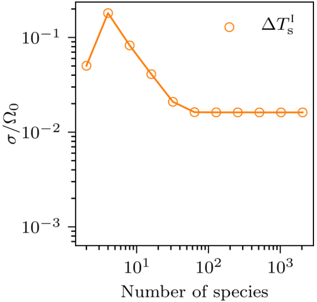
Number of Species

Which is the number of species that ensures the convergence of the linear phase?

$$\Delta T_s^{\mathrm{I}} = [10^{-4}, 10^{-1}]$$

$$\Delta T_s^{\mathrm{II}} = [10^{-4}, 1]$$





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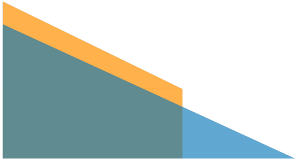
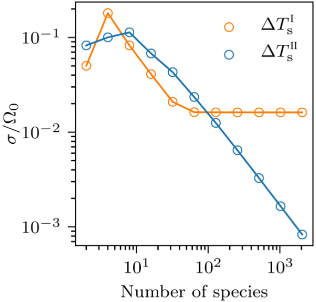
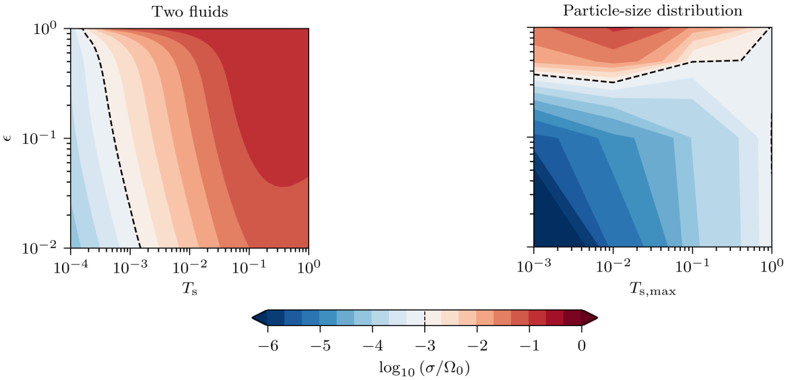




Upper Bounds for the Growth Rate



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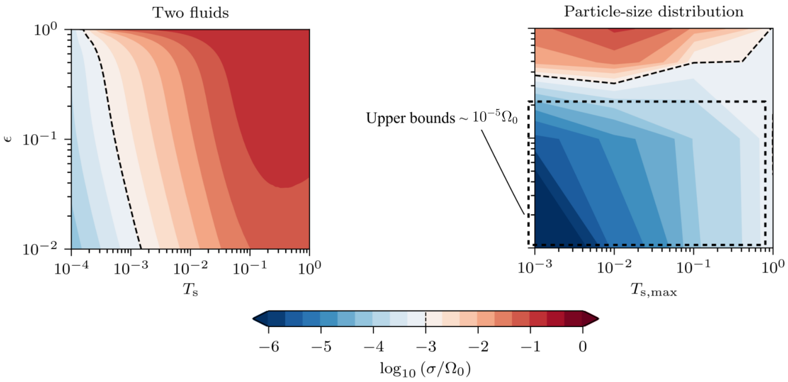

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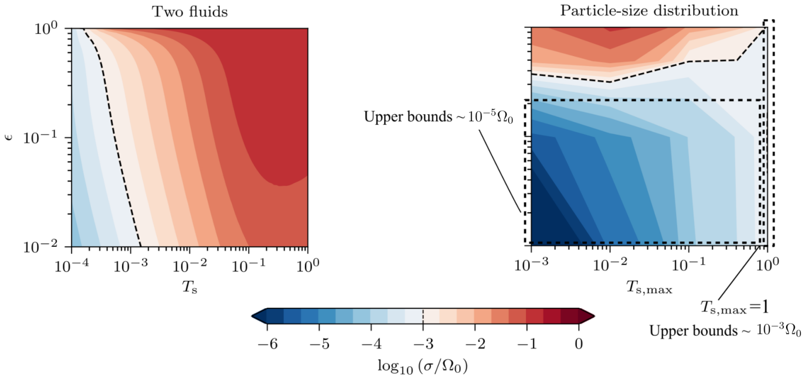

Conclusions

- For distributions with $\epsilon < 0.5$ the multispecies SI may grow on **secular** time scales.
- Distributions with $T_{\mathrm{s,max}} = 1$ show convergence of the linear phase for $\epsilon > 1$.
- For distributions with $\epsilon > 0.5$ and $T_{\mathrm{s,max}} \lesssim 10^{-2}$ the SI grows faster than the two-fluid case.

Conclusions

Question:

What are the constraints for particle-size distributions in PPDs?

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Take home message:

Unless we can identify mechanisms to produce mono disperse particle populations efficiently, the scope of the streaming instability may be narrowed down profoundly.