Dust settling in turbulent protoplanetary disks

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January 2019
Diversity of planetary systems

As of January 2019:

- >3800 extra-solar planets detected
- 2900 planetary systems
- Wide range of orbital configurations
Life in other worlds?

TRAPPIST-1 system

Credit: NASA/JPL/CalTech

Illustration
Planets form in accretion disks around young stars

The result is readily observed, what about earlier stages, e.g. ‘e’ or even ‘d’?
A new era: observing planet formation

V1094 Sco

Elias 24

(van Terwisga et al. 2018)

(Dipierro et al. 2018)
Protoplanetary disks are \( \sim 99\% \) gas, \( \sim 1\% \) dust

Planets form from the solids (at least in core accretion)

Need to understand how dust grains evolve in the gaseous disk
Planetesimal formation require high dust-to-gas ratios

- Dust and pebbles can coagulate into large planetesimals if $\rho_{\text{dust}} \gtrsim \rho_{\text{gas}}$
- But $\rho_{\text{dust}}/\rho_{\text{gas}} \sim 1\%$ in the interstellar medium

\[
\frac{\rho_d}{\rho_g} \sim 0.01 \text{ (ISM)} \quad \text{HOW?} \quad \frac{\rho_d}{\rho_g} \sim 1 \text{ (planetesimal formation)}
\]
Enhancing the dust-to-gas ratio in protoplanetary disks

Dust settling?

Adapted from Chiang & Youdin (2010)
Yes... if the disk is laminar
Turbulence in protoplanetary disks

Newly (re)discovered sources of turbulence

- Zombie vortex instability (Marcus et al., 2015)
- Convective overstability (Klahr & Hubbard, 2014)
- Vertical shear instability (Nelson et al., 2013)

\[ \Omega = \Omega_{\text{Kep}}(R) + \Omega_{\text{corr}}(R, z) \]
Lifting dust particles by the VSI

Moderately turbulent disk
Lifting dust particles by the VSI

Strongly turbulent disk
Effect of particle size

Small particles remain well-mixed with gas: no settling
Effect of metallicity ($\Sigma_{\text{dust}}/\Sigma_{\text{gas}}$)

- Increasing the overall dust content makes the system ‘heavy’ → more difficult for VSI to stir up

\[ \Sigma_d = 0.01 \Sigma_g \]

\[ \Sigma_d = 0.1 \Sigma_g \]
More particles settle further

(Lin, submitted)
Summary

- Dust-gas dynamics is fundamental to planetesimal/planet formation.
- Turbulence can hinder planetesimal formation by preventing dust settling.
- Larger and/or more particles can overcome turbulent stirring in PPDs due to the vertical shear instability.
Student opportunities

I am looking for motivated Masters/PhD students to work on various topics in planet formation theory. Potential projects include:

- Dust-gas dynamics in protoplanetary disks
- Disk-planet interaction and orbital migration
- Fluid instabilities and structures in accretion disks

Please contact me for more information!

Thank you

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