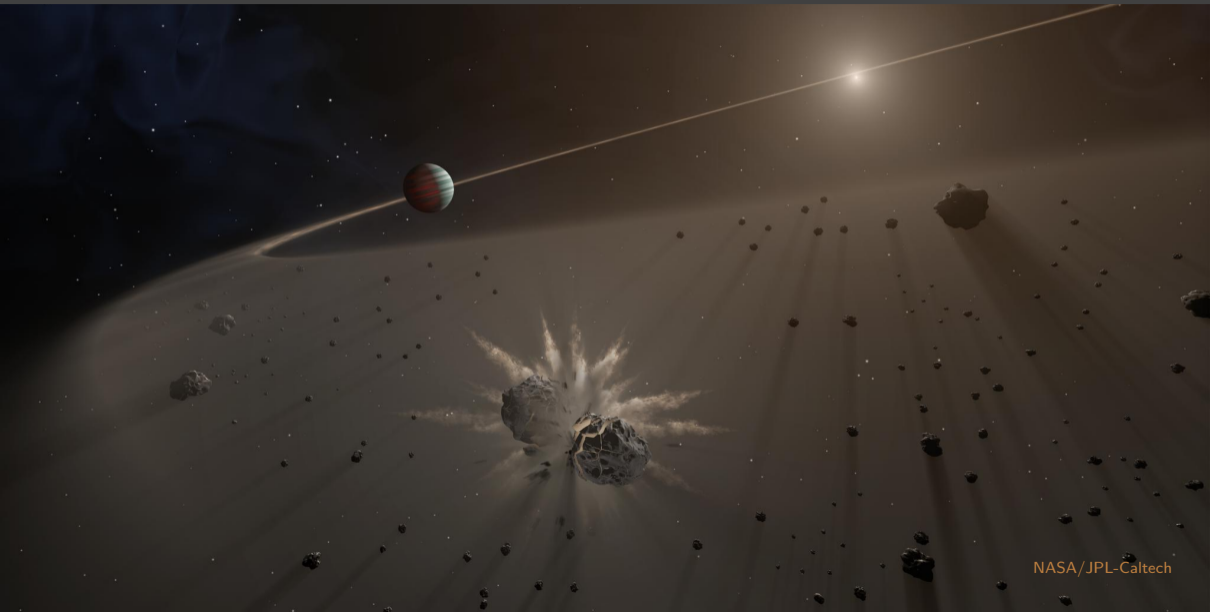


Debris-disc dynamics

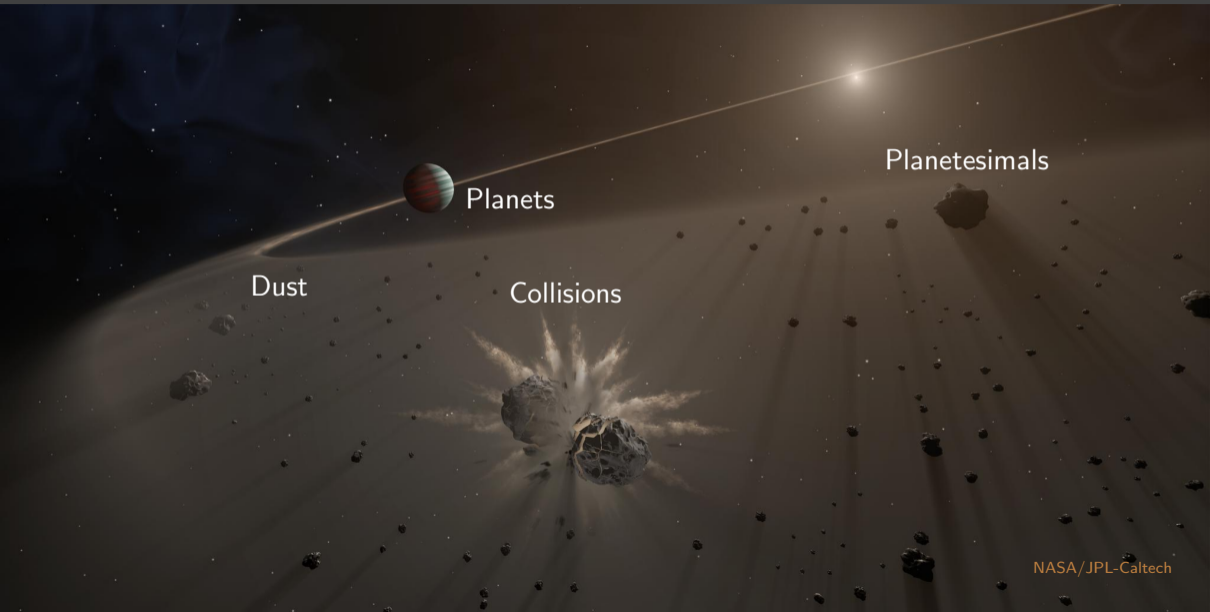


Tim D. Pearce

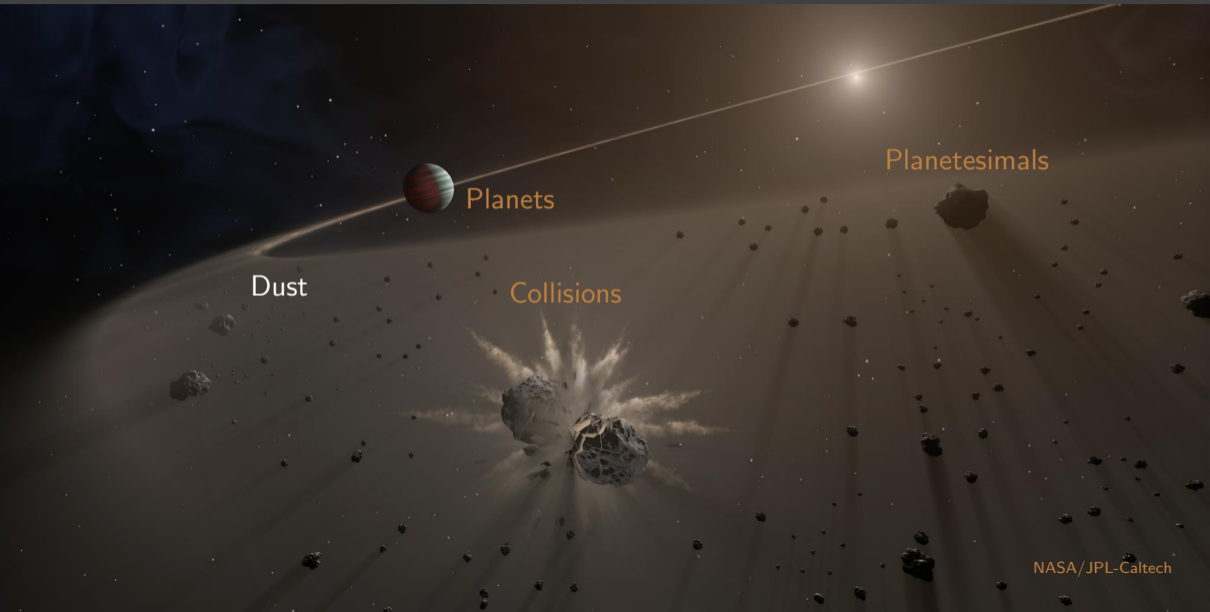
Debris-disc dynamics



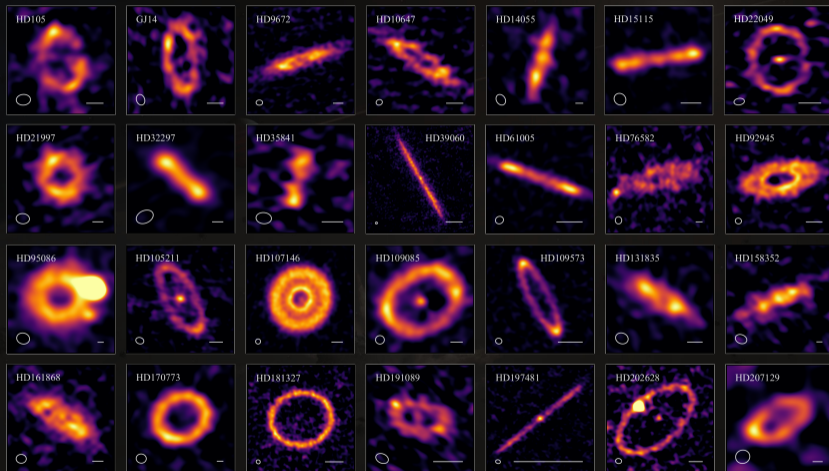
Debris-disc dynamics



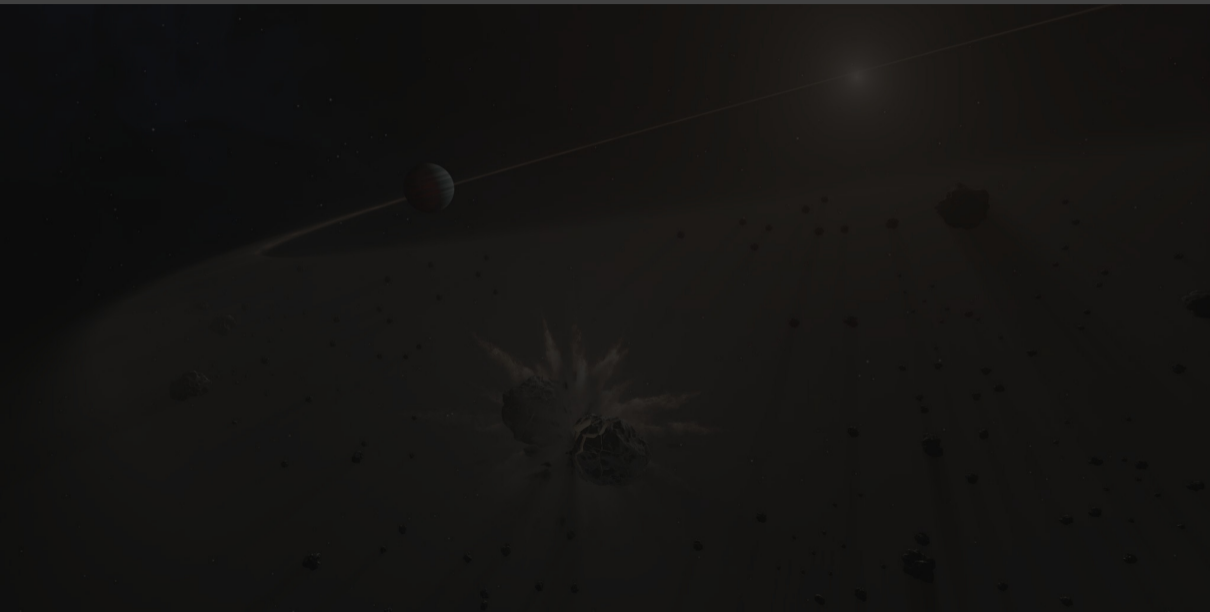
Debris-disc dynamics



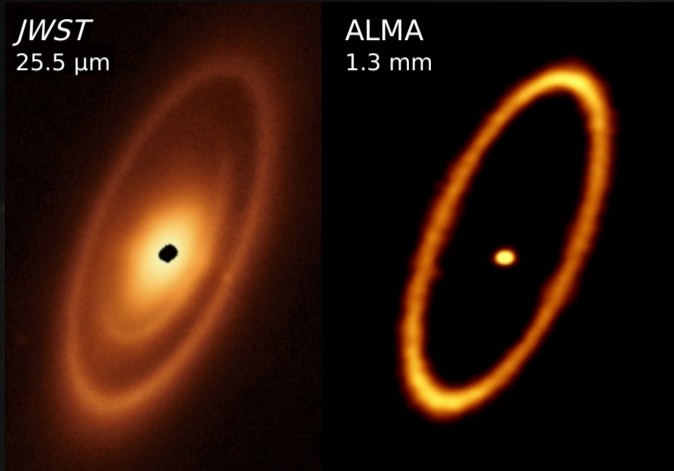
We see dust



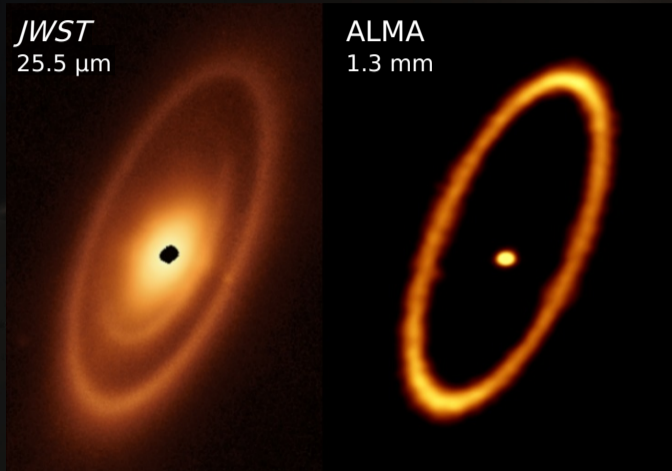
Observed grains have size similar to the observing wavelength



Observed grains have size similar to the observing wavelength

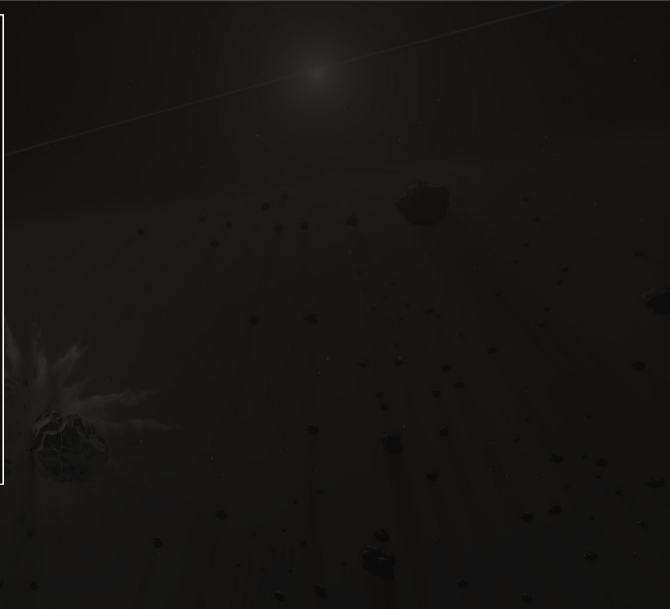


Observed grains have size similar to the observing wavelength

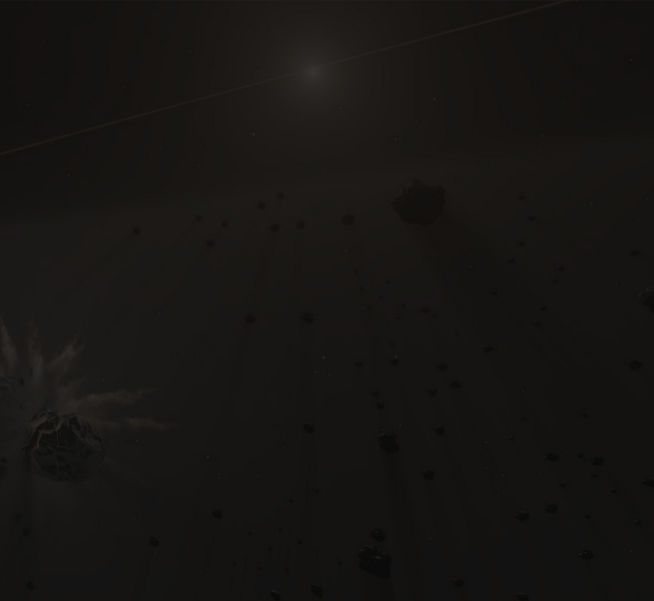
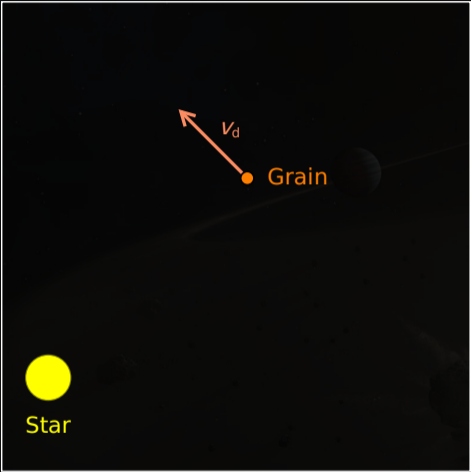


⇒ Debris discs look different at different grain sizes

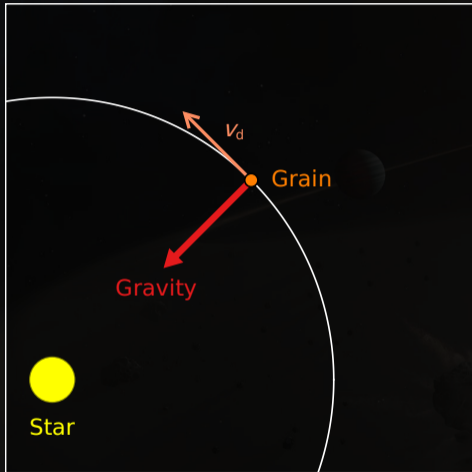
Forces on dust grains



Forces on dust grains



Forces on dust grains

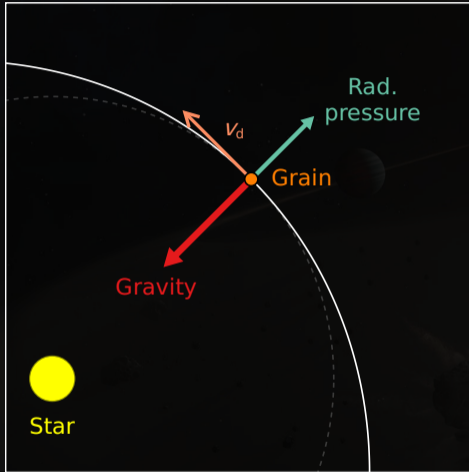


Forces:

- Gravity

$$\mathbf{F}_{\text{grav}} = -\frac{GM_* m_d}{r^2} \hat{\mathbf{r}}$$

Forces on dust grains

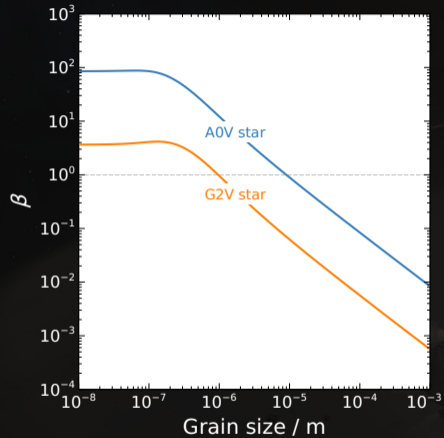


Forces:

- Gravity
- Radiation pressure

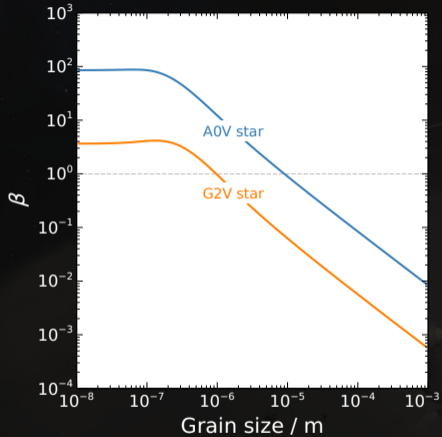
$$\mathbf{F} = \underbrace{\mathbf{F}_{\text{grav}}(1 - \beta)}_{\text{Gravity + rad. pressure}}$$

Forces on dust grains



$$\mathbf{F} = \underbrace{\mathbf{F}_{\text{grav}}(1 - \beta)}_{\text{Gravity + rad. pressure}}$$

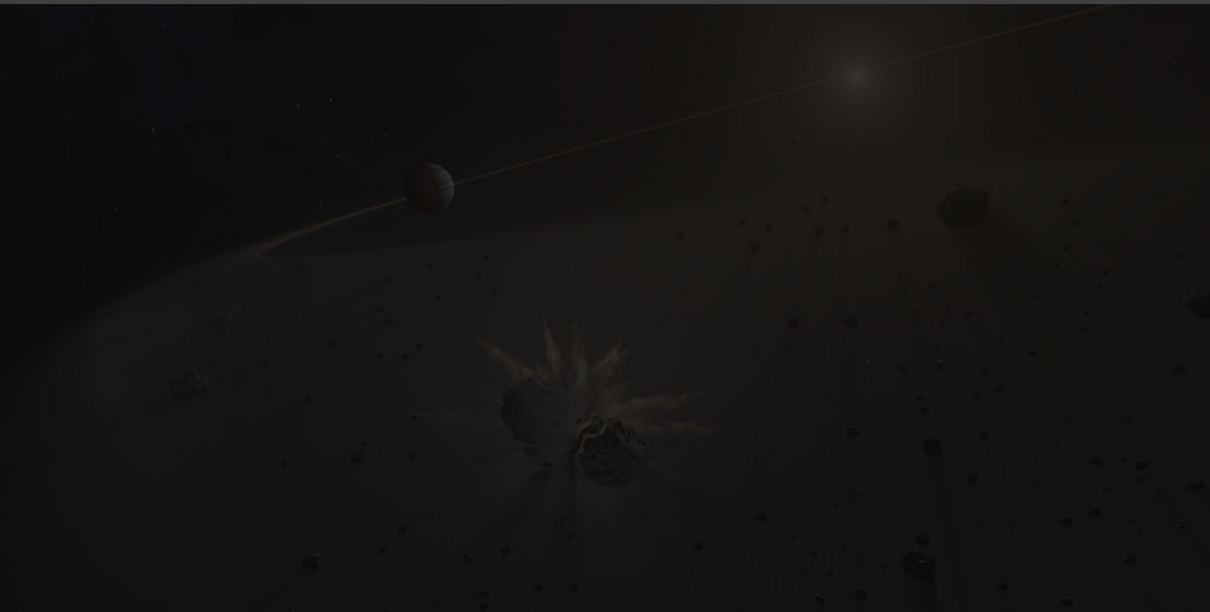
Forces on dust grains



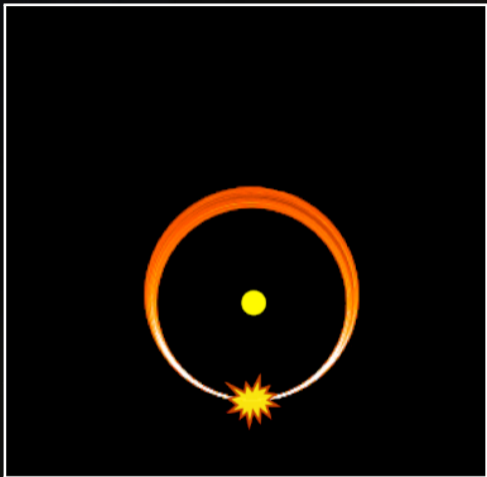
- Smaller grains: higher β
- Brighter stars: higher β

$$\mathbf{F} = \underbrace{\mathbf{F}_{\text{grav}}(1 - \beta)}_{\text{Gravity + rad. pressure}}$$

Small grains have more-extended distributions

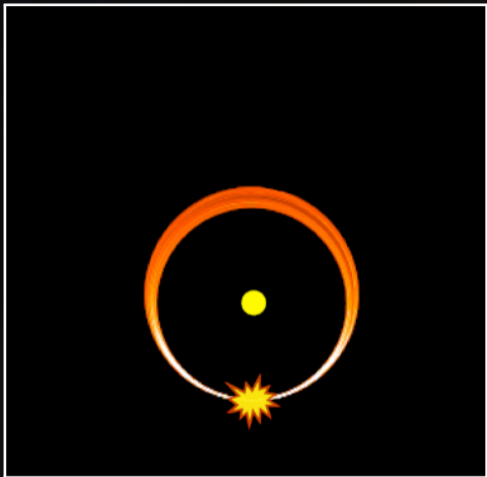


Small grains have more-extended distributions

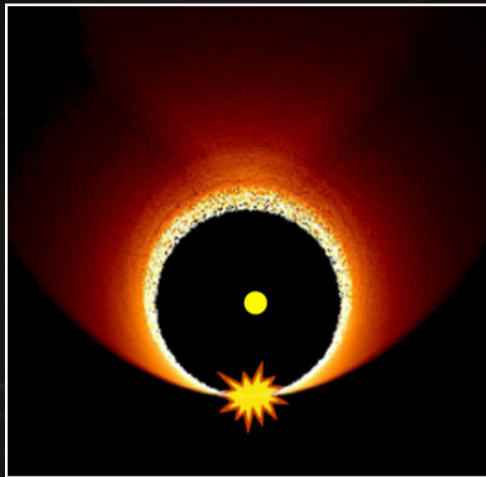


Large grains

Small grains have more-extended distributions

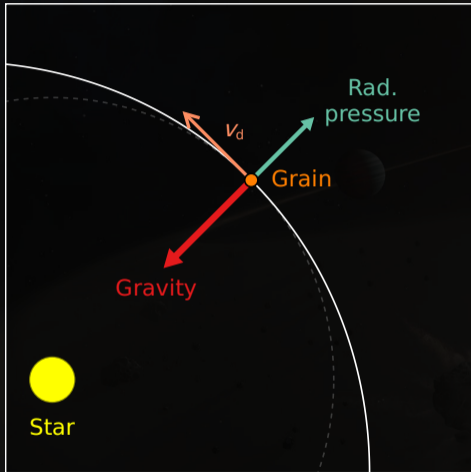


Large grains



Small grains

Forces on dust grains

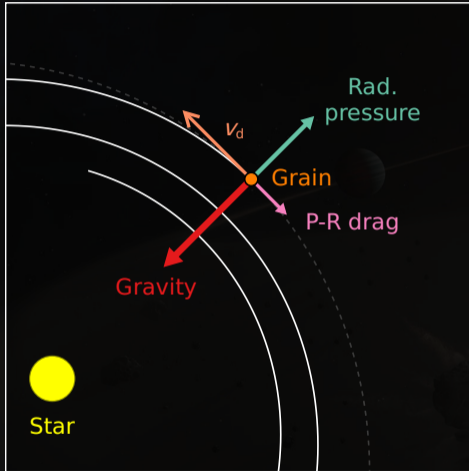


Forces:

- Gravity
- Radiation pressure

$$\mathbf{F} = \underbrace{\mathbf{F}_{\text{grav}}(1 - \beta)}_{\text{Gravity + rad. pressure}}$$

Forces on dust grains

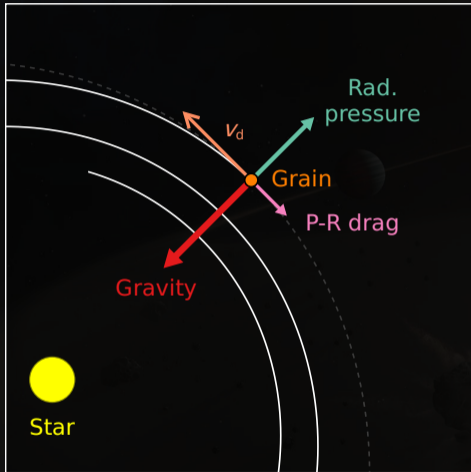


Forces:

- Gravity
- Radiation pressure
- Poynting-Robertson (P-R) drag

$$\mathbf{F} = \underbrace{\mathbf{F}_{\text{grav}}(1 - \beta)}_{\text{Gravity + rad. pressure}} - \underbrace{\beta |\mathbf{F}_{\text{grav}}| \left(\frac{\dot{r}_d}{c} \hat{\mathbf{r}} + \frac{\mathbf{v}_d}{c} \right)}_{\text{P-R drag}}$$

Forces on dust grains

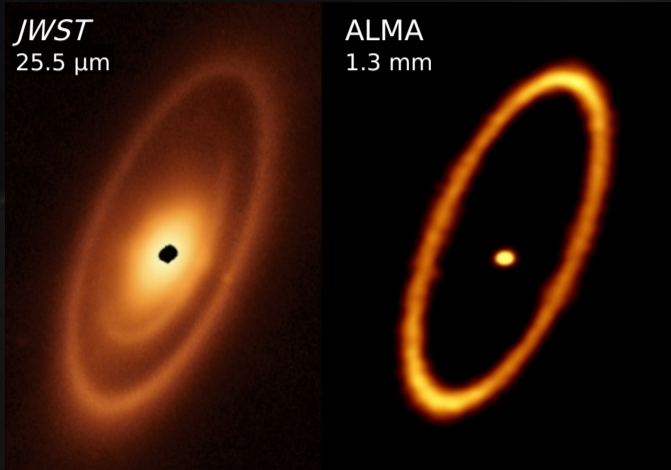


Forces:

- Gravity
- Radiation pressure
- Poynting-Robertson (P-R) drag
- Stellar winds, Lorentz force, gas drag, spin forces...

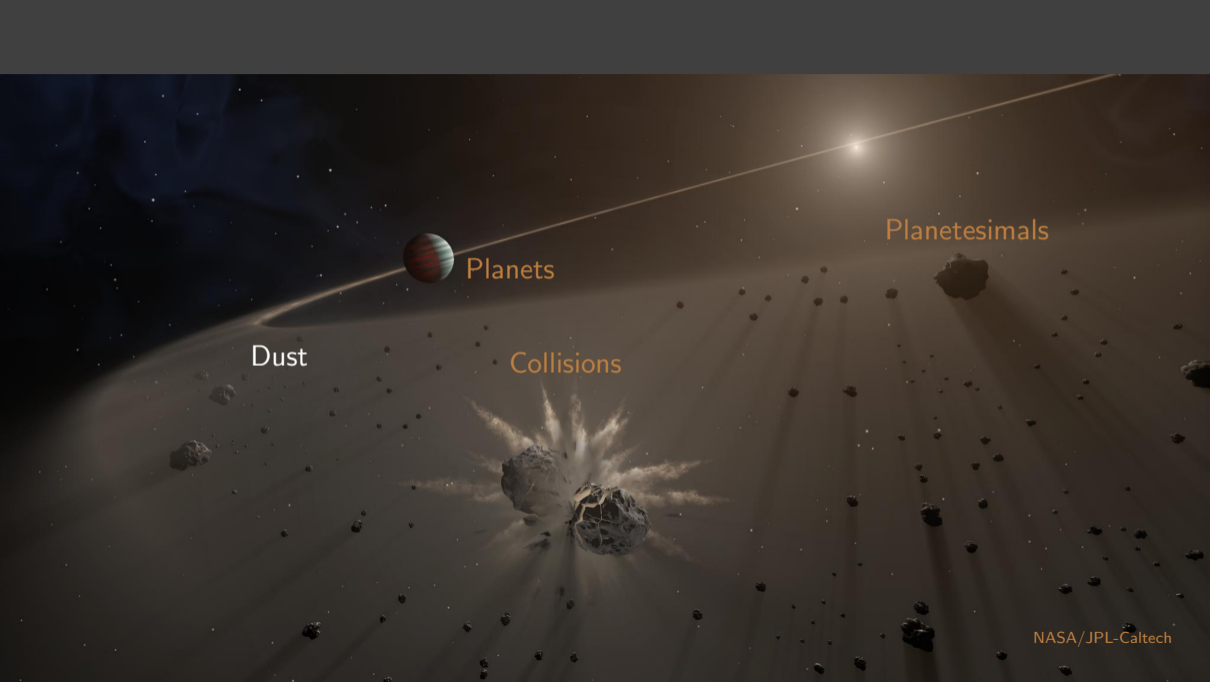
$$\mathbf{F} = \underbrace{\mathbf{F}_{\text{grav}}(1 - \beta)}_{\text{Gravity + rad. pressure}} - \underbrace{\beta |\mathbf{F}_{\text{grav}}| \left(\frac{\dot{r}_d}{c} \hat{\mathbf{r}} + \frac{\mathbf{v}_d}{c} \right)}_{\text{P-R drag}} + \dots$$

Small grains have more-extended distributions



But dust should only survive for ~ 1 Myr.

So where does the dust come from?

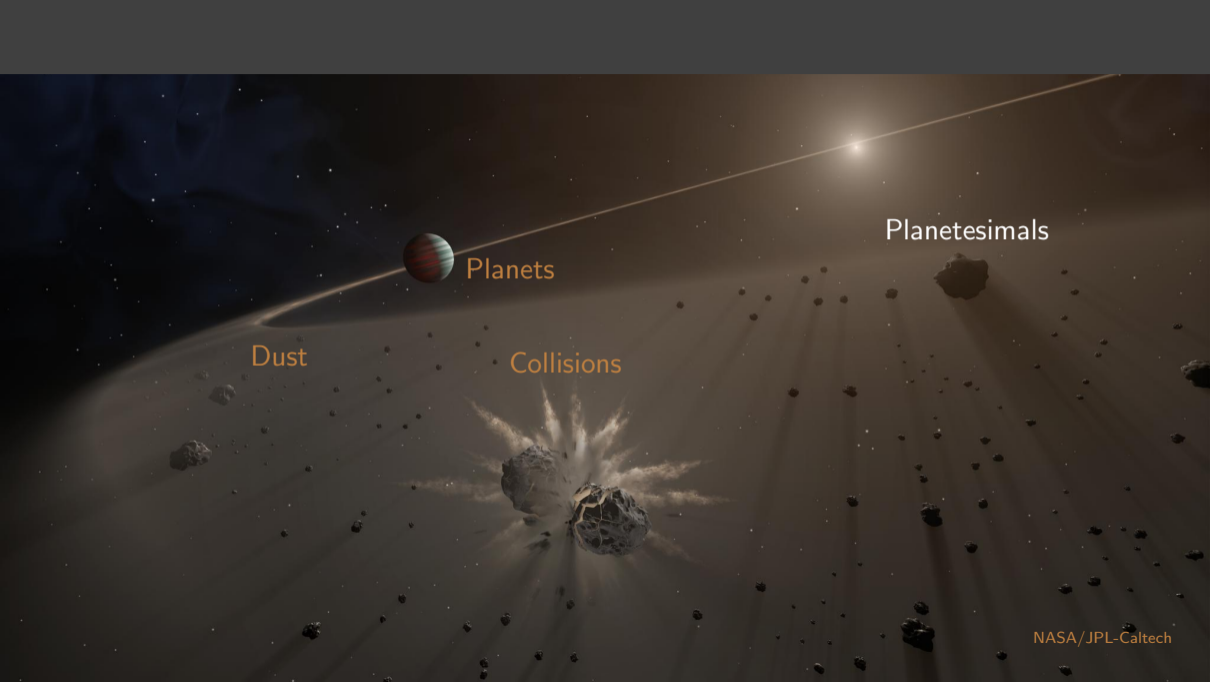


Dust

Collisions

Planets

Planetesimals



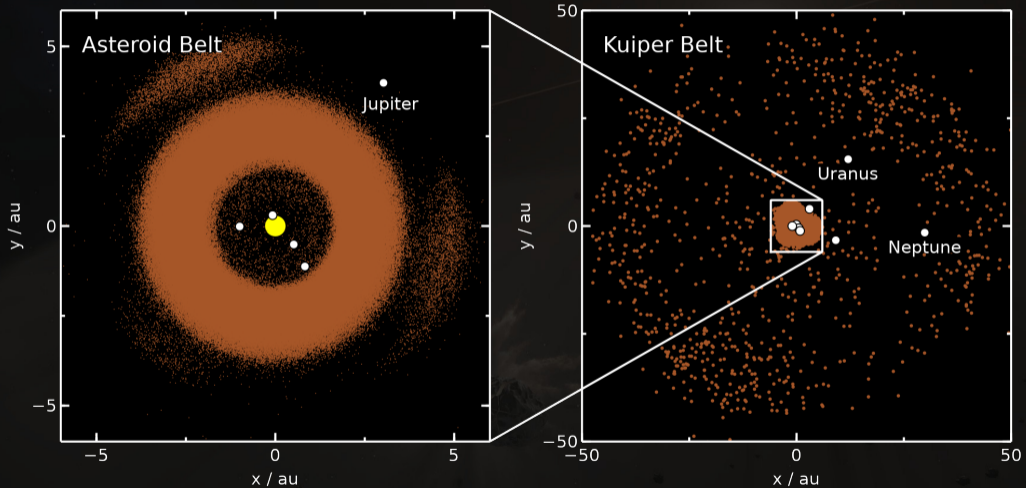
Dust

Collisions

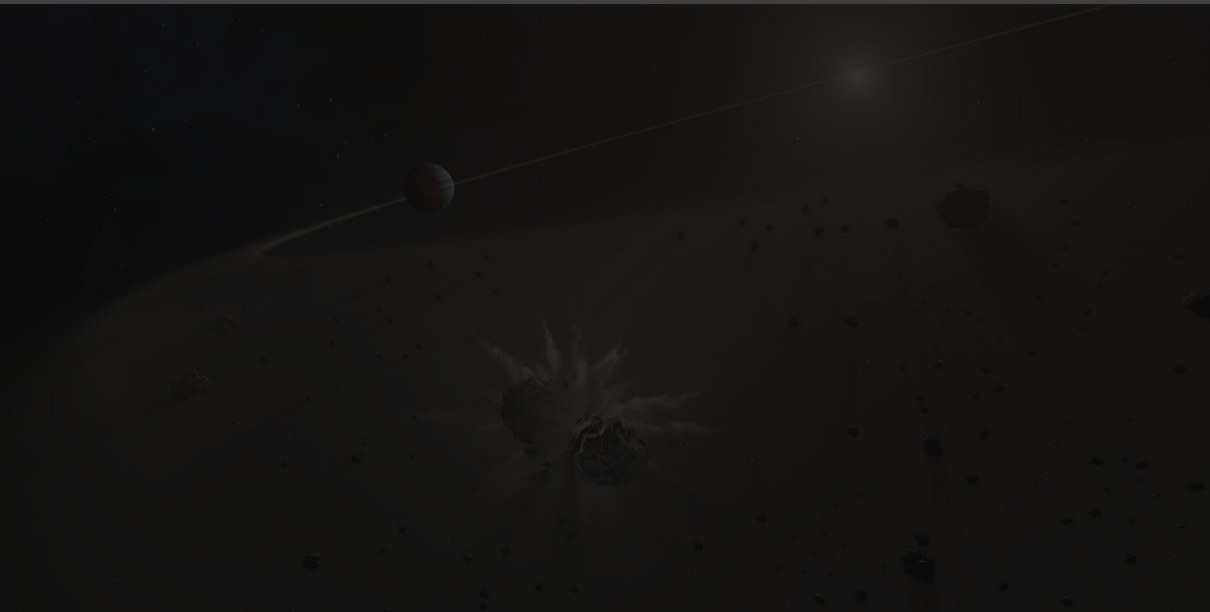
Planets

Planetesimals

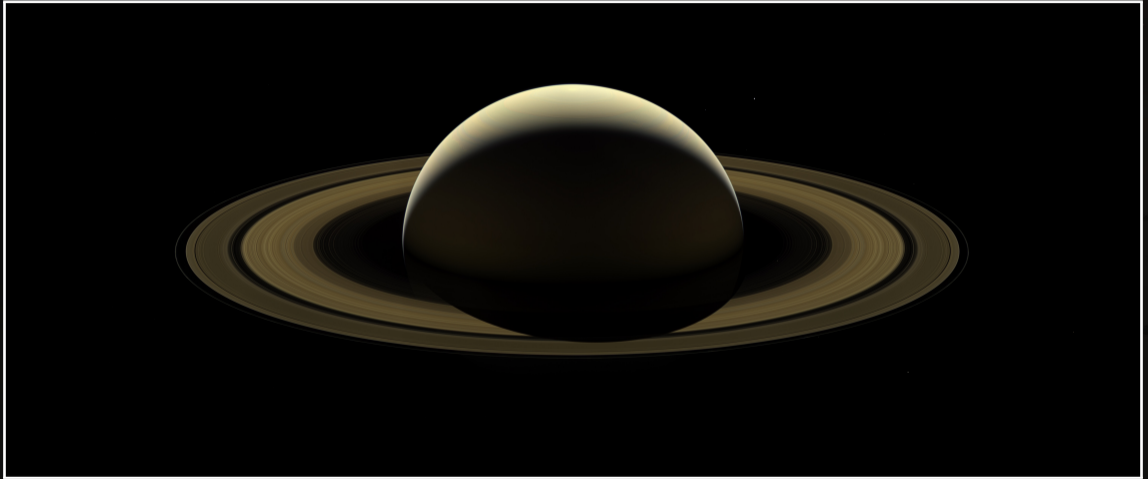
Planetesimals in the Solar System



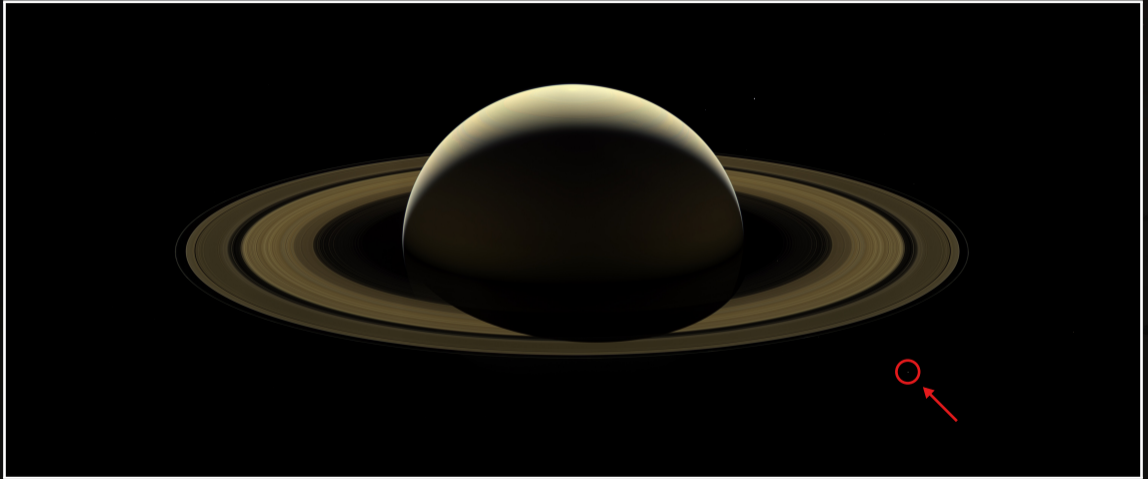
But we cannot see extrasolar planetesimals



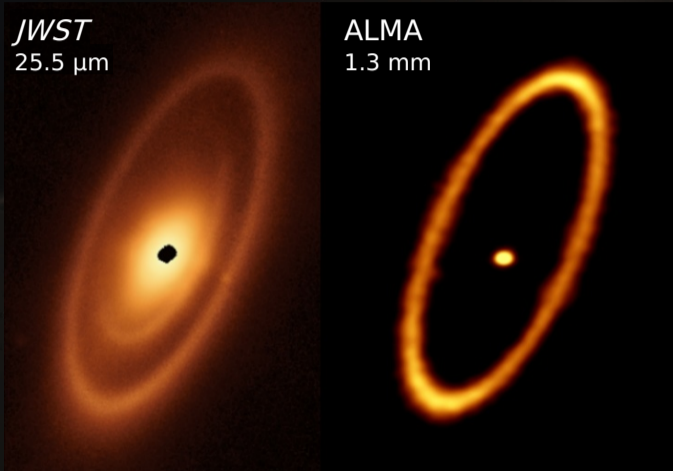
But we cannot see extrasolar planetesimals

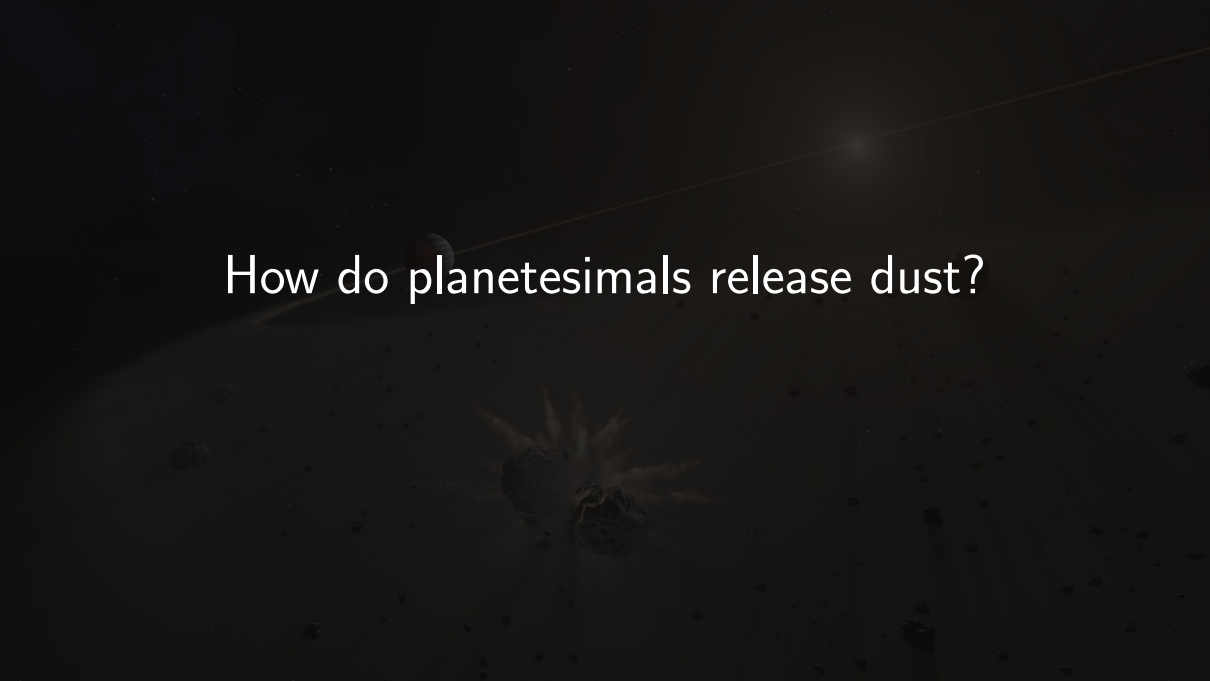


But we cannot see extrasolar planetesimals

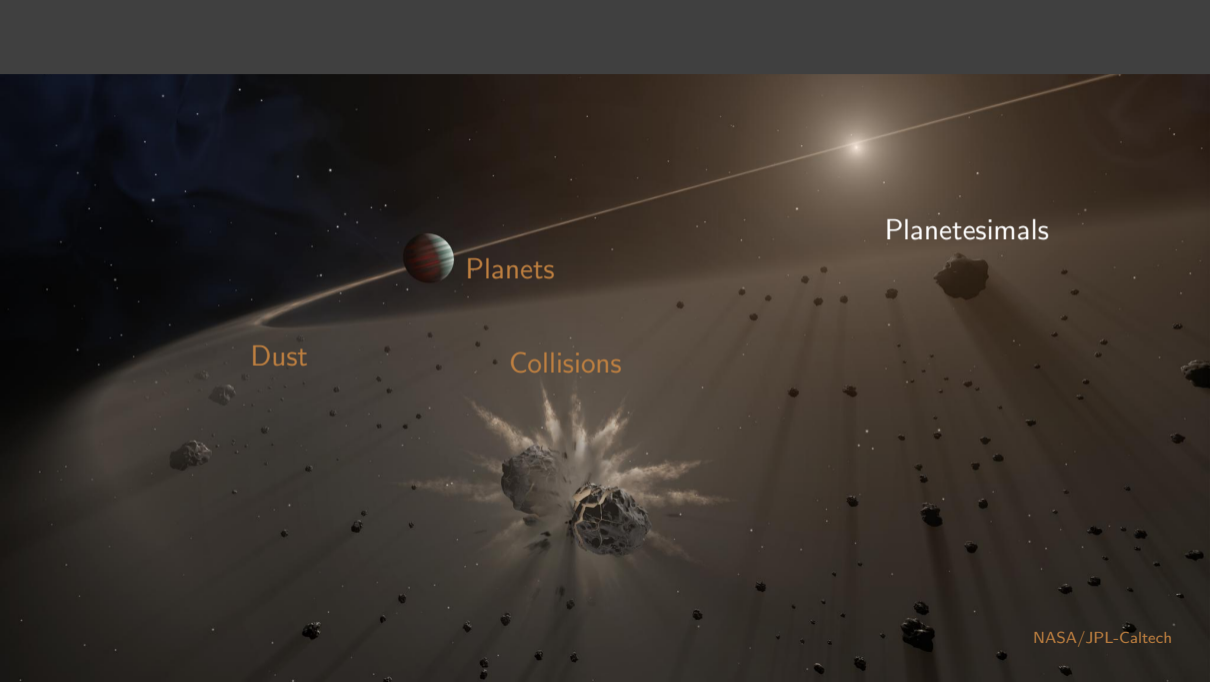


Large grains trace planetesimals



A dark space background with a bright star in the upper right, a planet in the upper left, and a comet with a long tail in the lower center. The text "How do planetesimals release dust?" is centered in white.

How do planetesimals release dust?

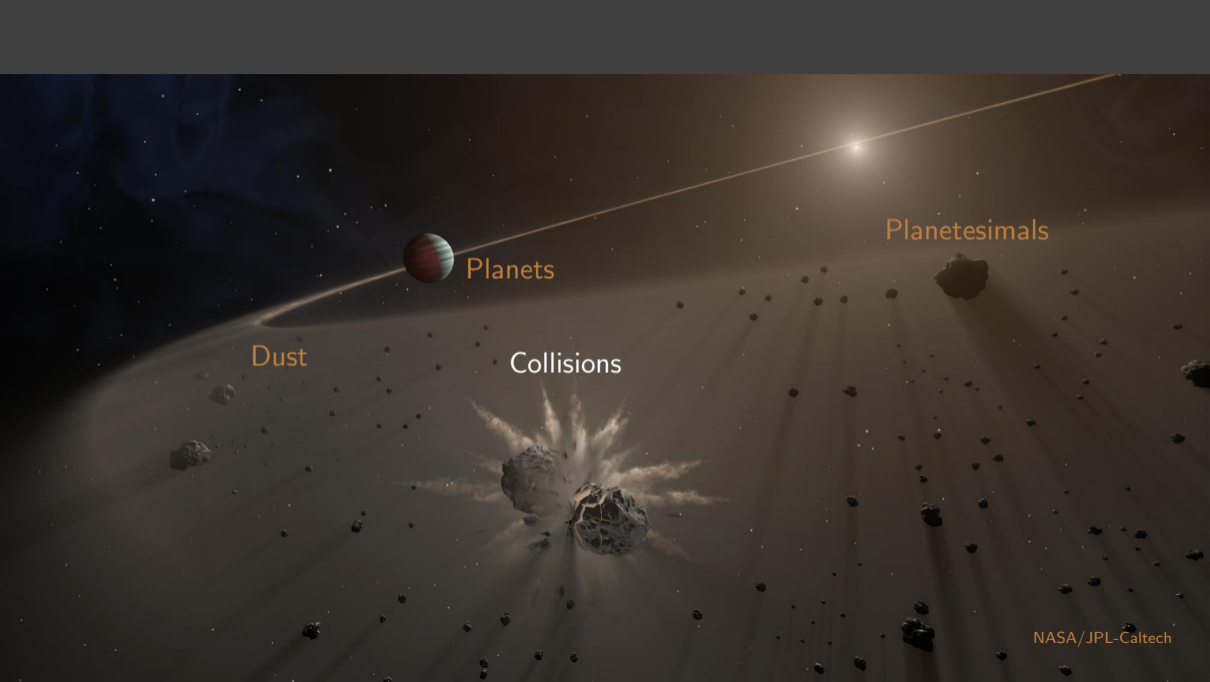


Planets

Planetesimals

Dust

Collisions



Dust



Planets

Collisions

Planetesimals

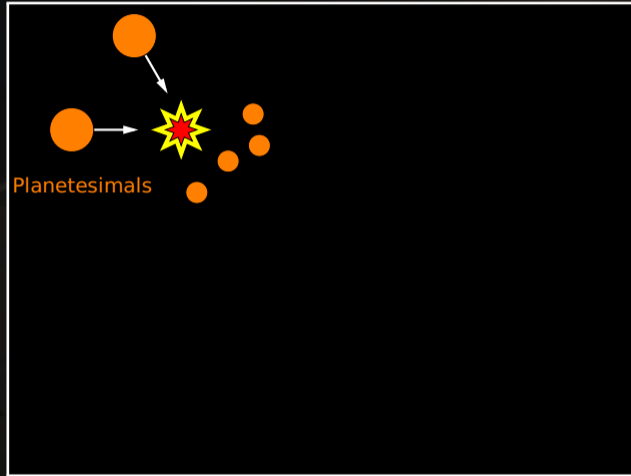
Collisional cascade



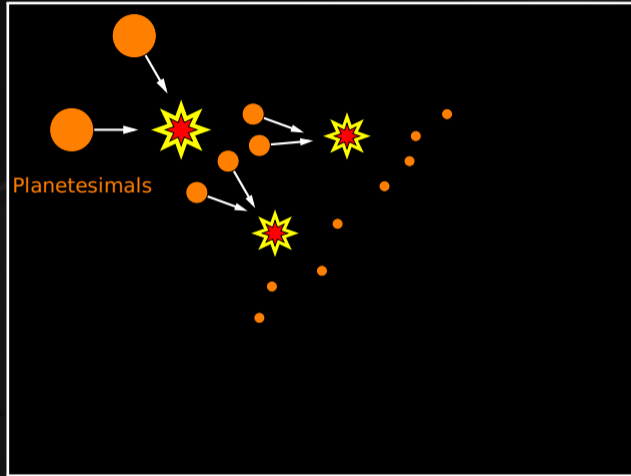
Collisional cascade



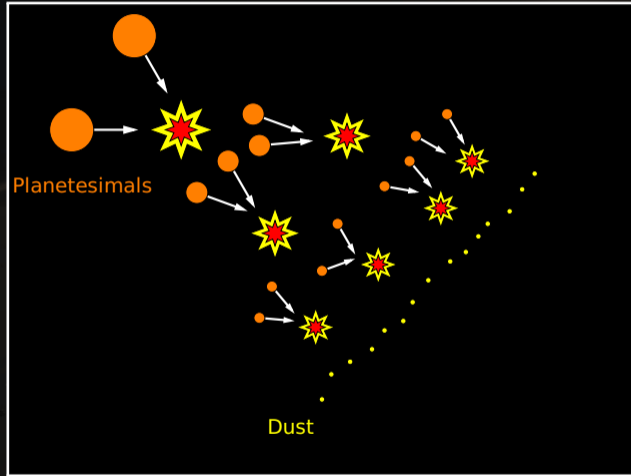
Collisional cascade



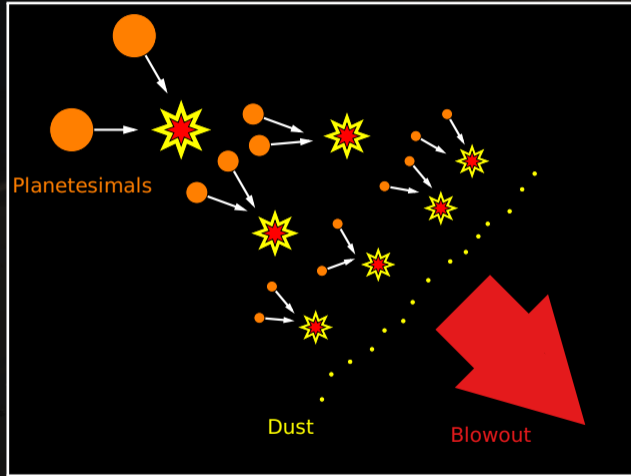
Collisional cascade



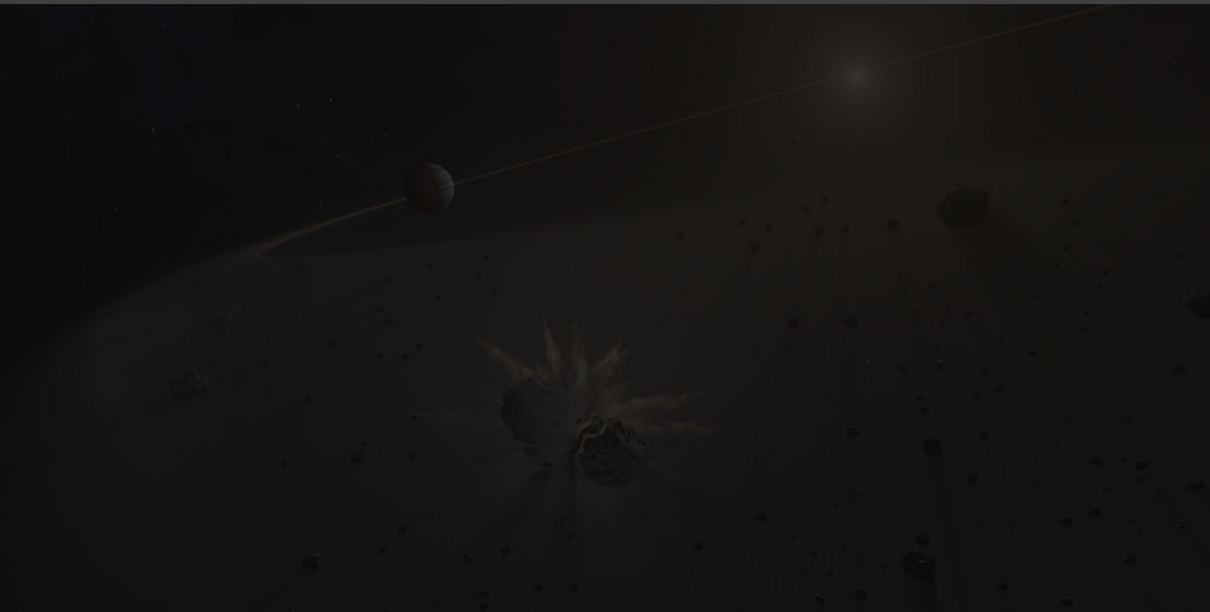
Collisional cascade



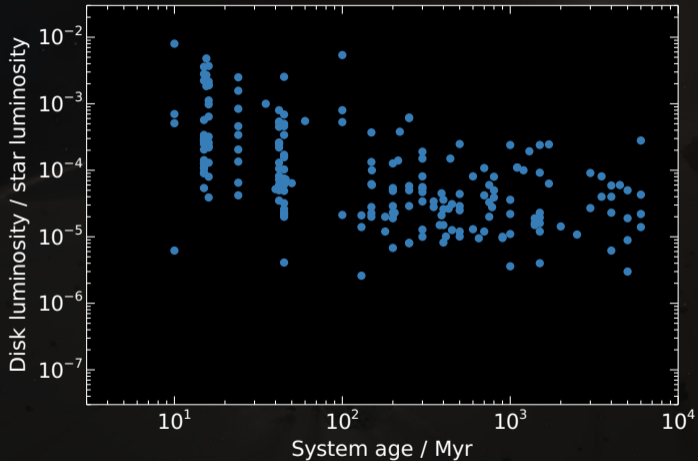
Collisional cascade



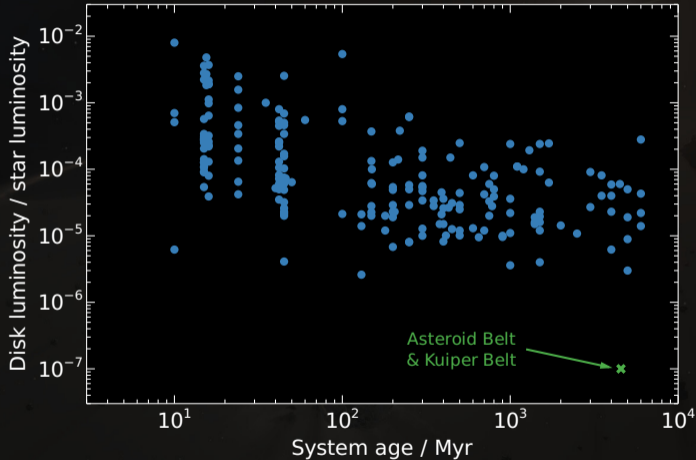
Debris discs lose mass and get fainter over time



Debris discs lose mass and get fainter over time



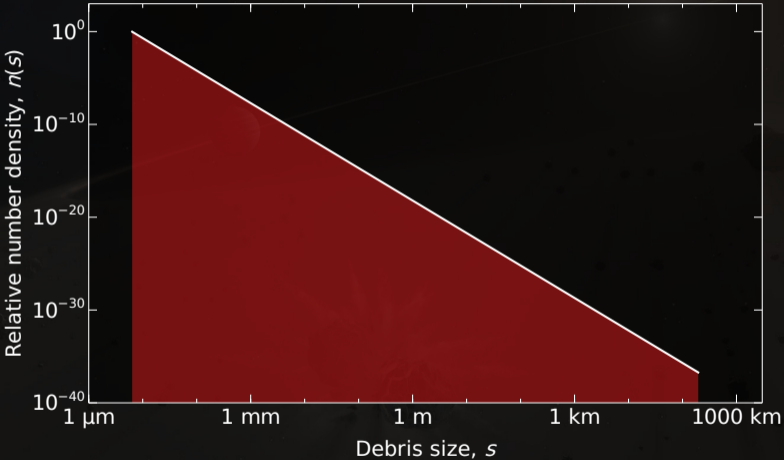
Debris discs lose mass and get fainter over time



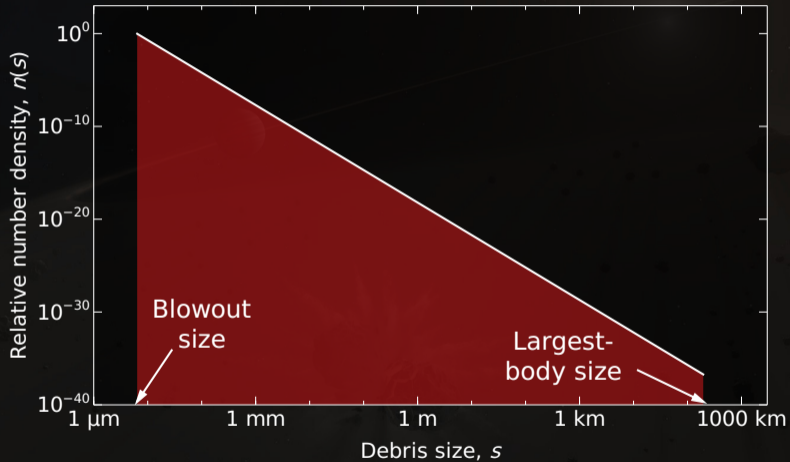
Size distribution



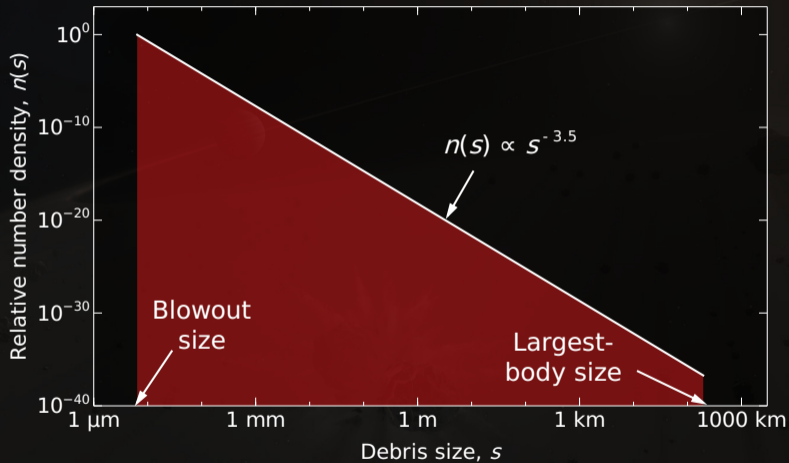
Size distribution



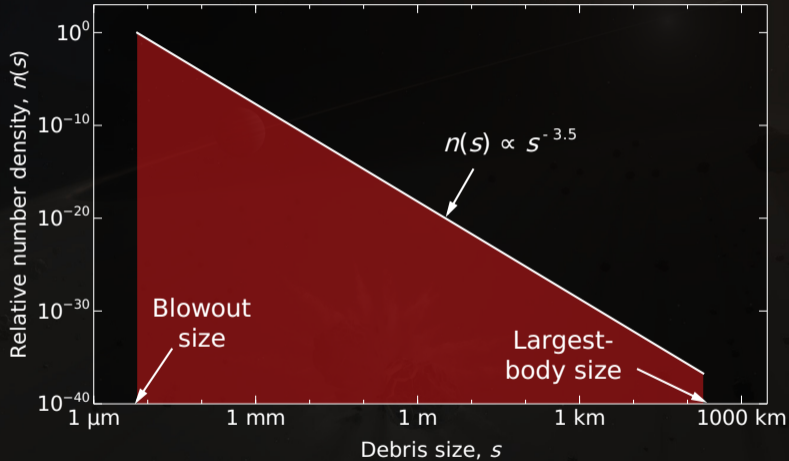
Size distribution



Size distribution

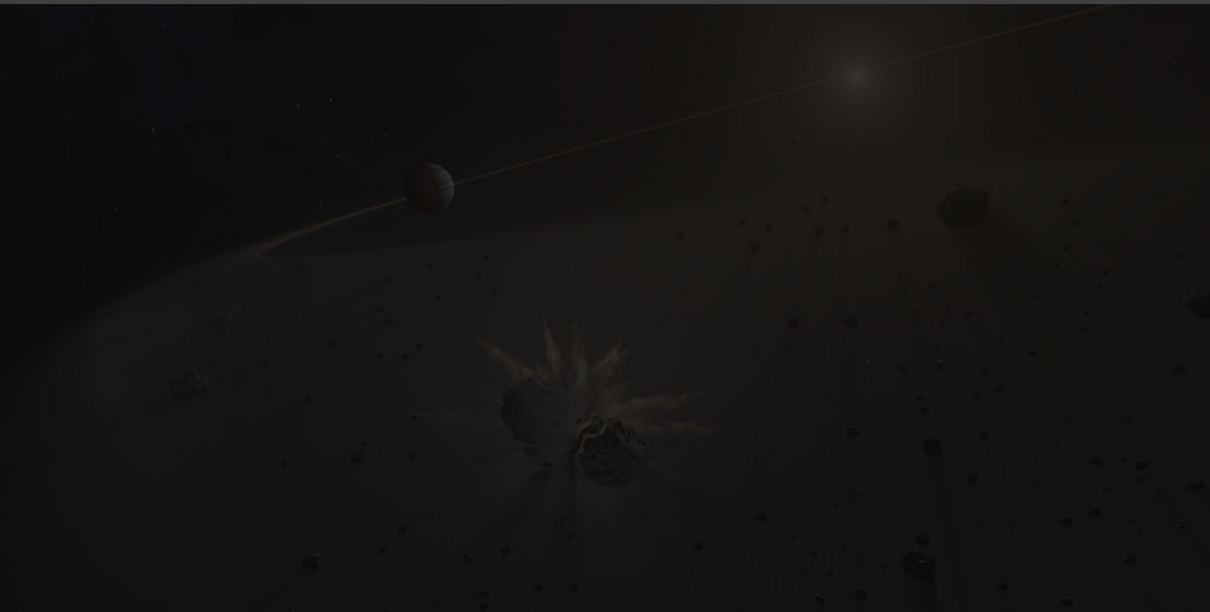


Size distribution



⇒ Smallest bodies dominate emission, largest dominate mass

Stirring



Stirring



Stirring



Stirring mechanisms:

- Self stirring

Stirring



Stirring mechanisms:

- Self stirring
- Flyby stirring

Stirring



Stirring mechanisms:

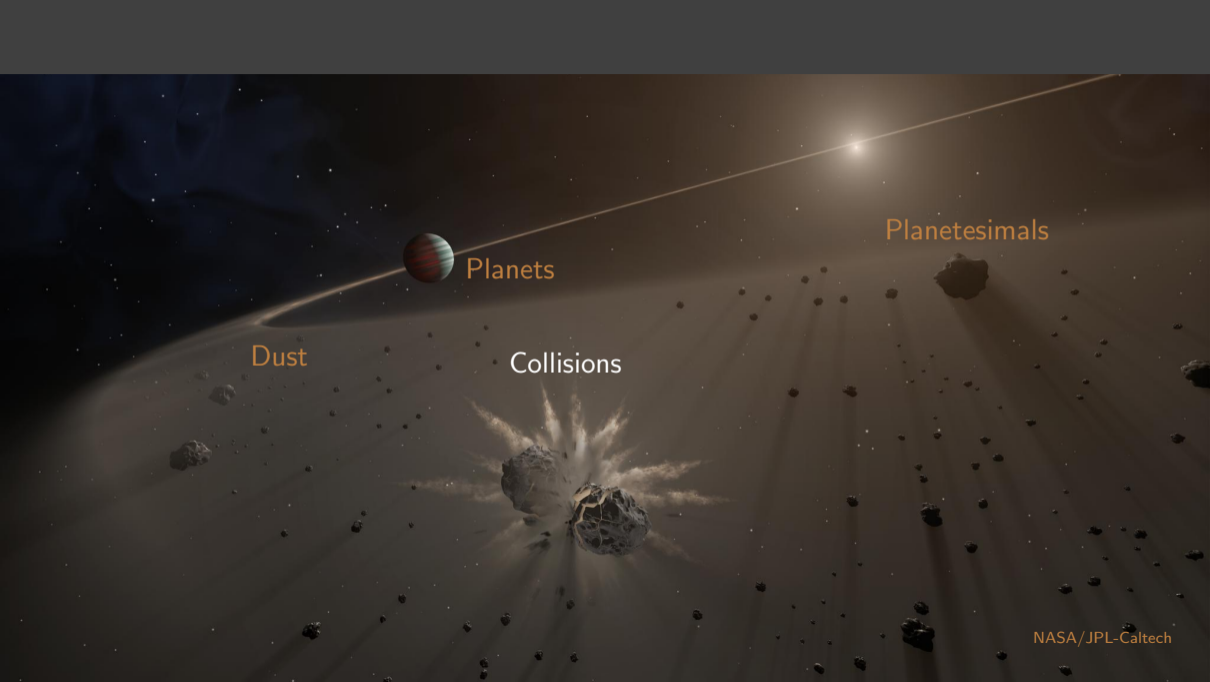
- Self stirring
- Flyby stirring
- Pre stirring

Stirring



Stirring mechanisms:

- Self stirring
- Flyby stirring
- Pre stirring
- Planet stirring

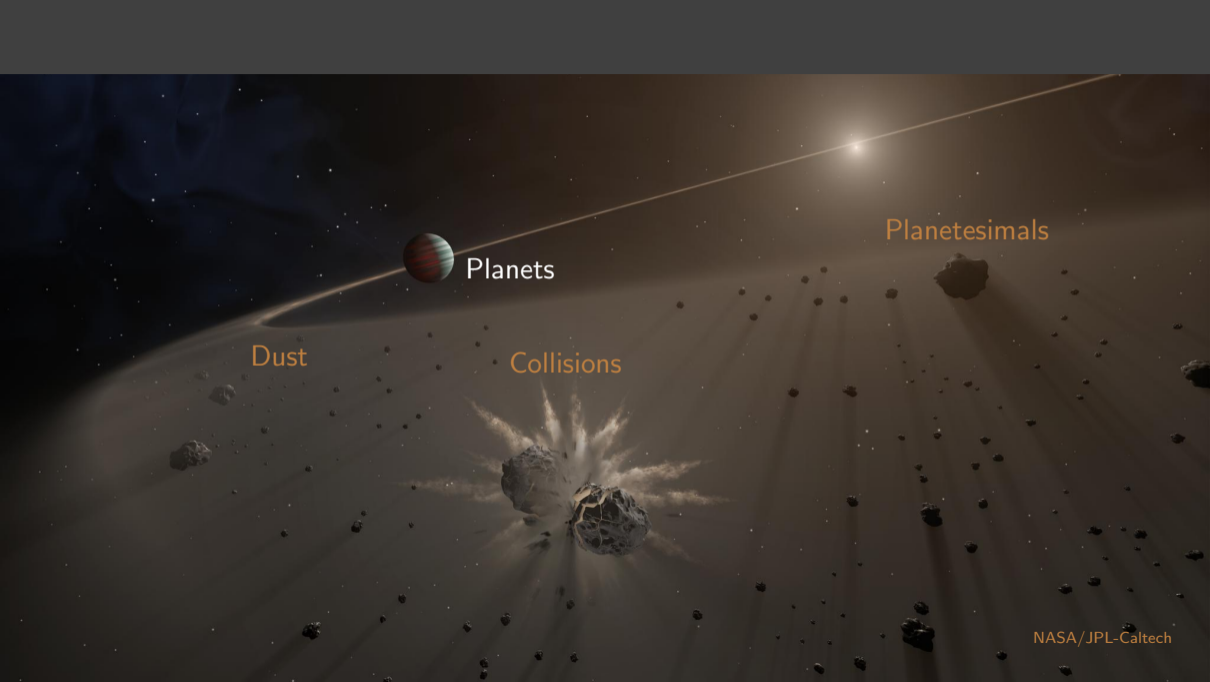


Dust

Collisions

Planets

Planetesimals



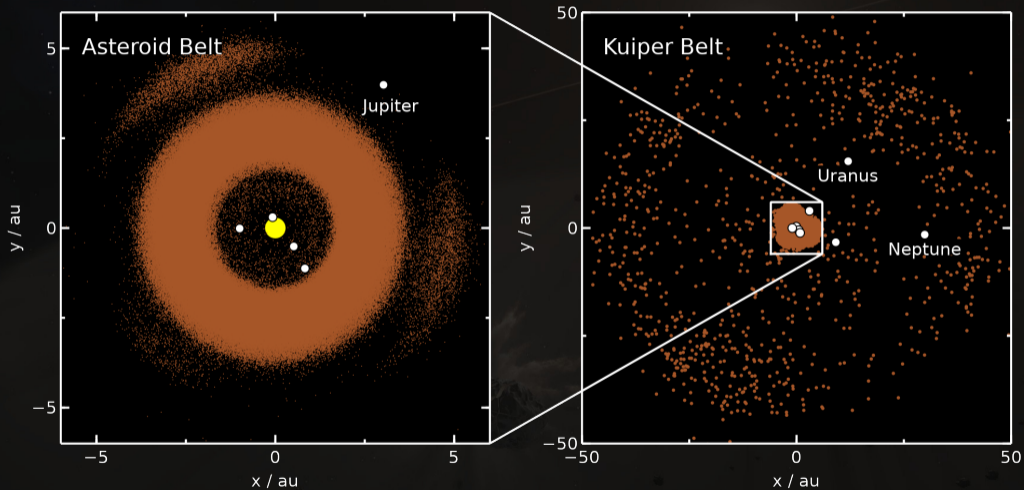
Planets

Planetesimals

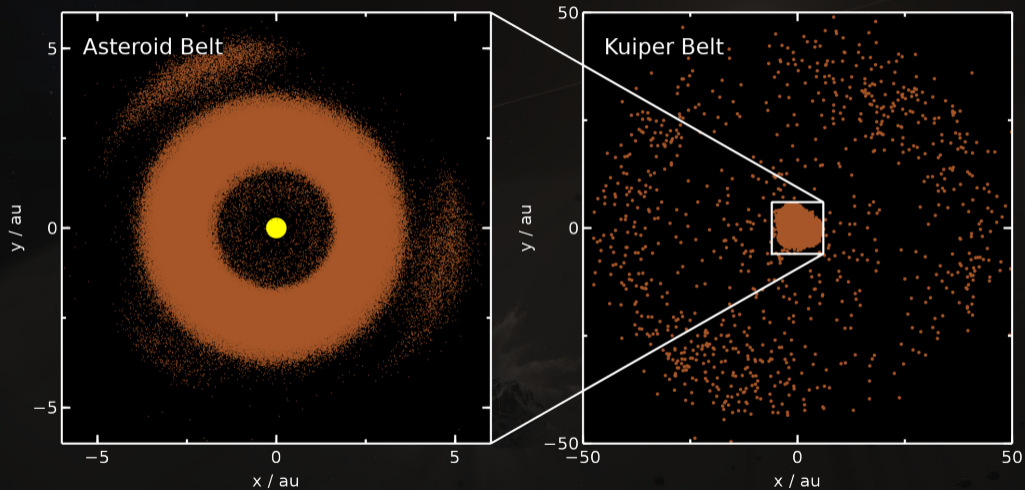
Dust

Collisions

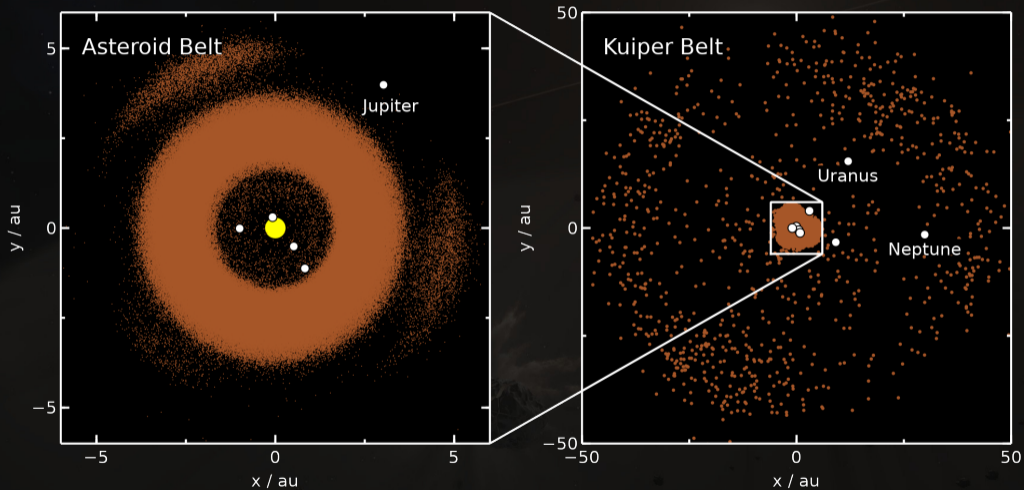
Planets and debris interact in the Solar System



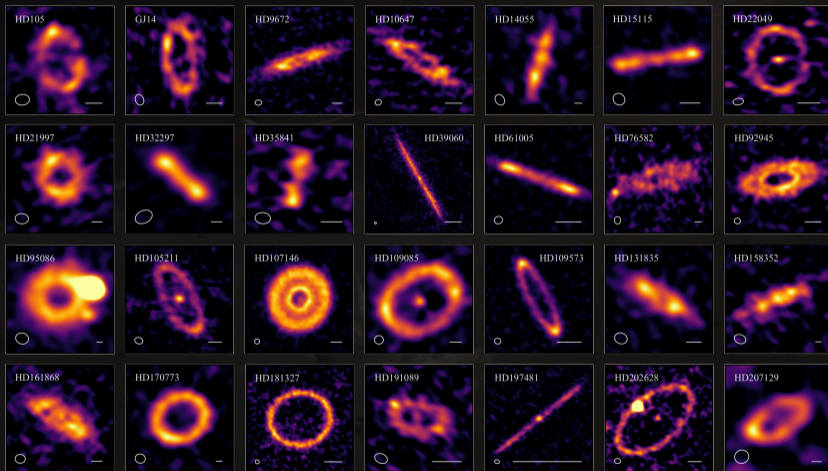
Planets and debris interact in the Solar System

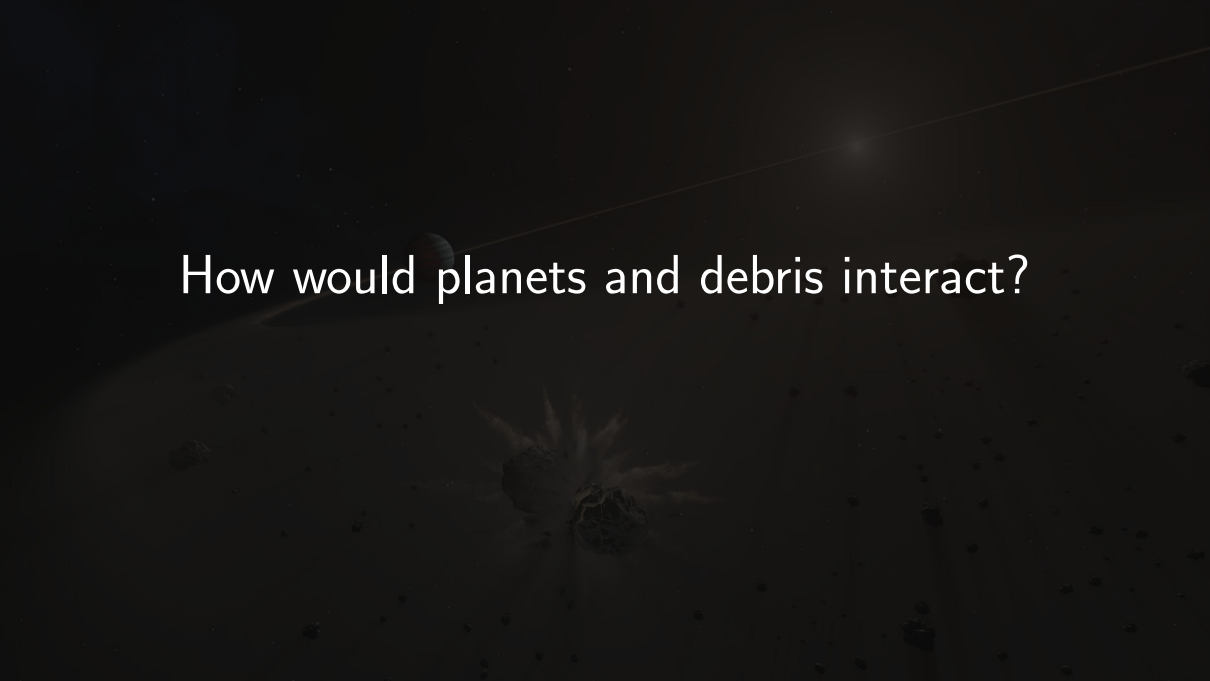


Planets and debris interact in the Solar System



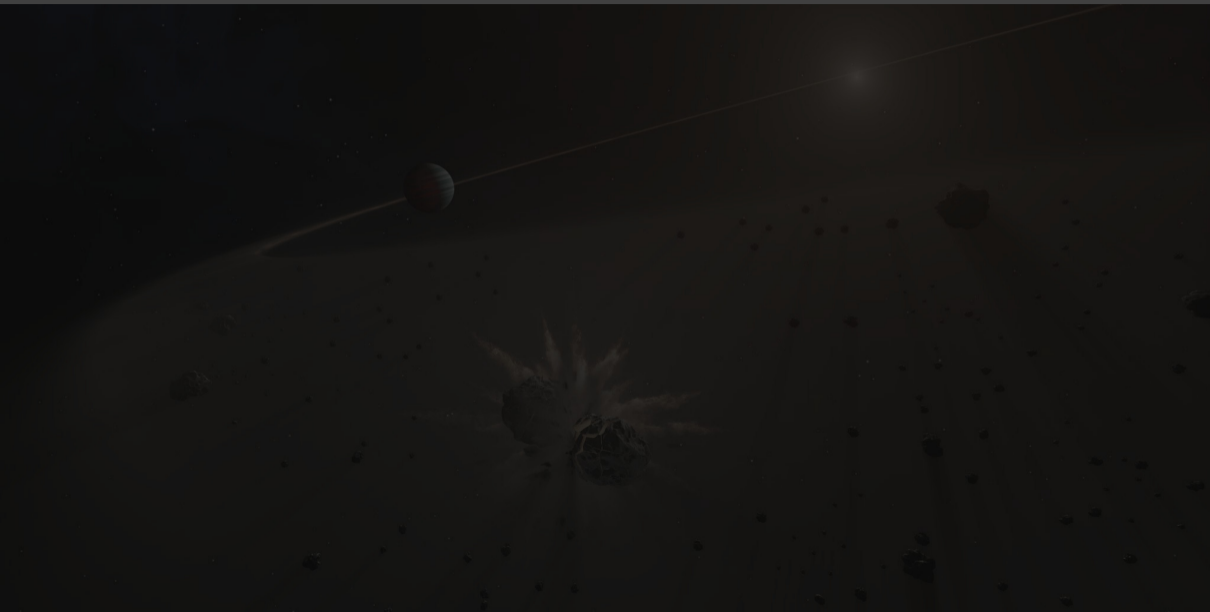
Do planets interact with extrasolar debris too?



A dark space scene with a bright star in the upper right, a planet in the upper left, and a debris field in the lower center. The text "How would planets and debris interact?" is centered in white.

How would planets and debris interact?

1. Planets can scatter nearby debris



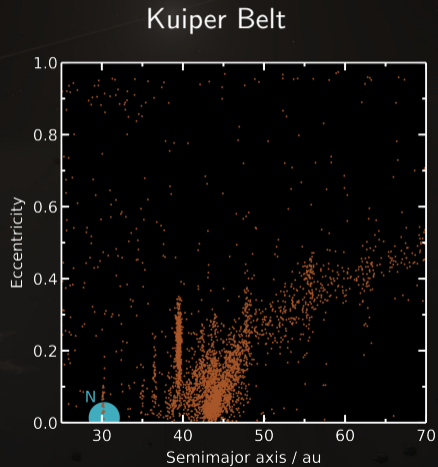
1. Planets can scatter nearby debris



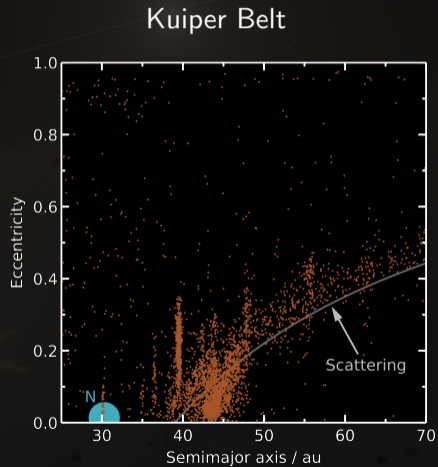
1. Planets can scatter nearby debris



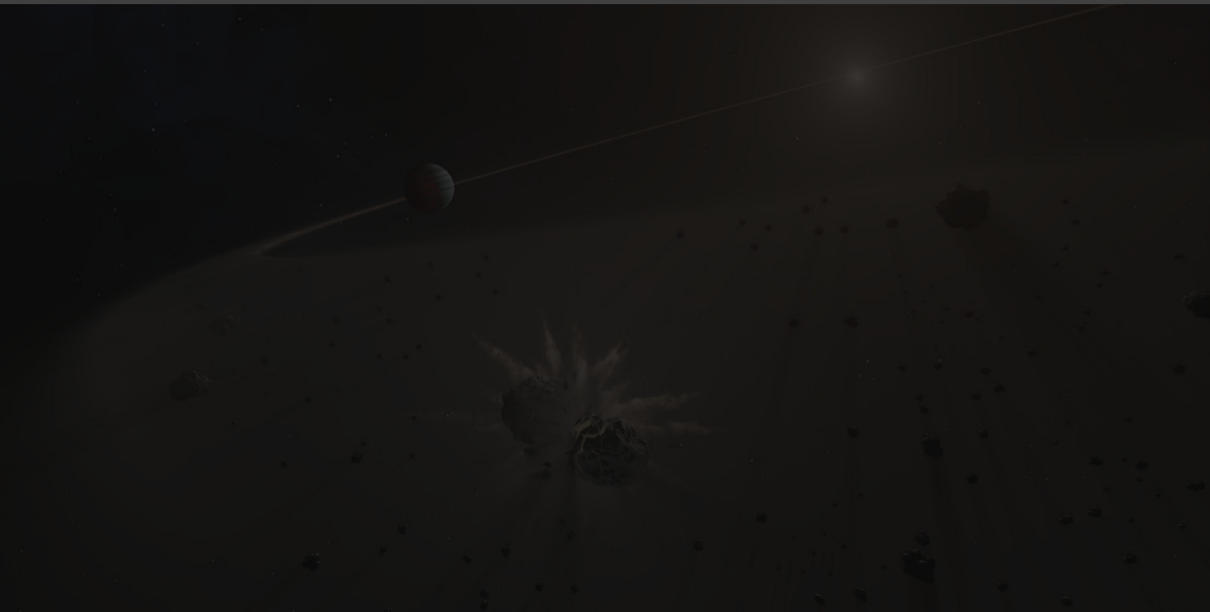
1. Planets can scatter nearby debris



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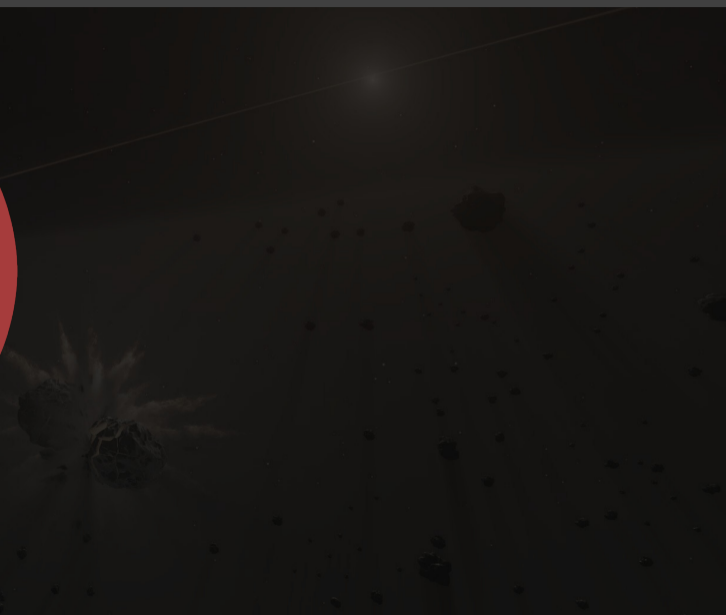
2. Planets can make discs **eccentric**



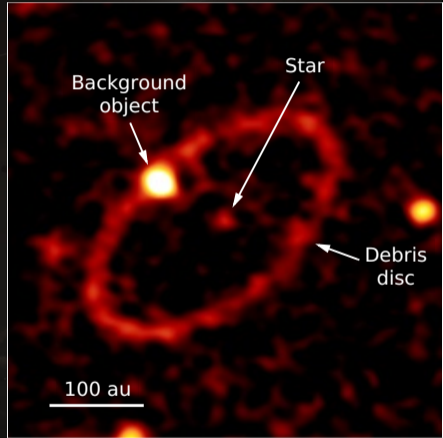
2. Planets can make discs **eccentric**



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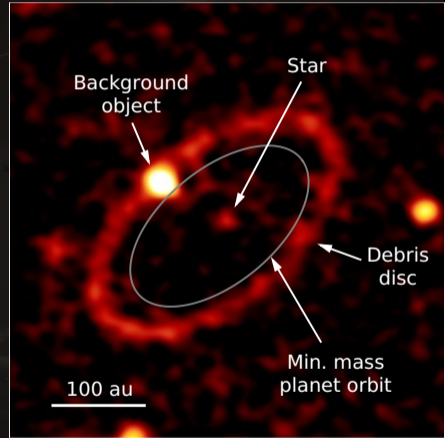
2. Planets can make discs **eccentric**



2. Planets can make discs **eccentric**



ALMA: Faramaz et al. 2019

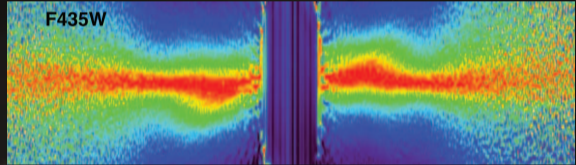


Planet parameters: Pearce et al. 2022

3. Planets can warp discs



3. Planets can warp discs



β Pic: Golimowski et al. 2006

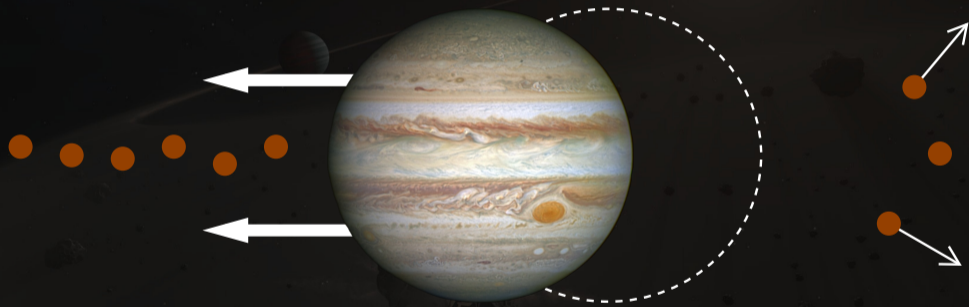
4. Planets can stir discs



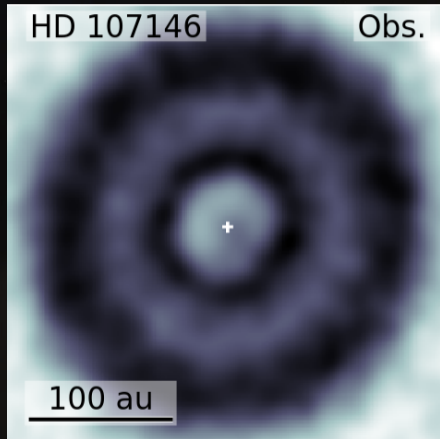
5. Debris can make planets migrate



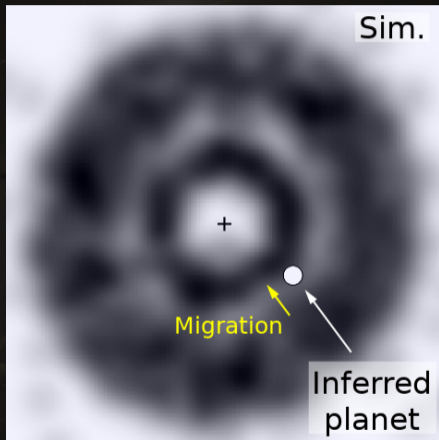
5. Debris can make planets migrate



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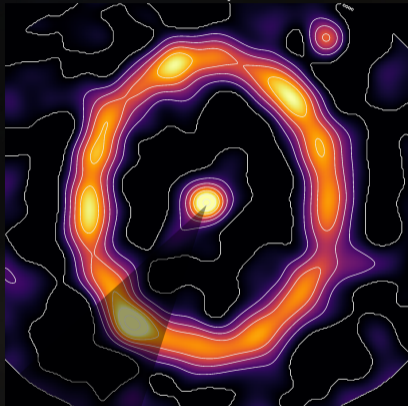
Marino et al. 2018



Friebe, Pearce & Löhne 2022

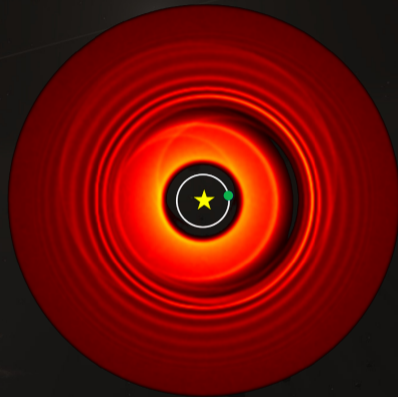
6. Planets can do other stuff too

Clumps



Booth et al. 2023

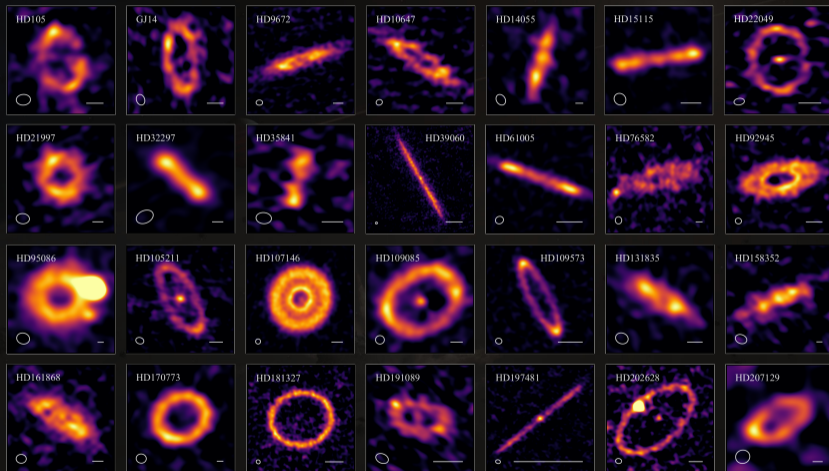
Gaps and spirals



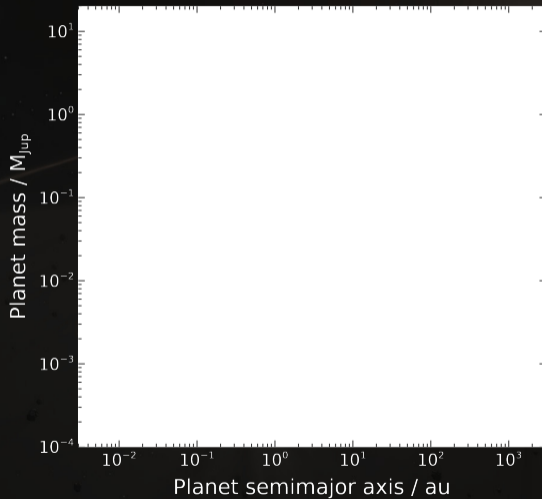
Sefilian, Rafikov & Wyatt 2021

See also: Ida, Larwood & Burkert 2000; Kirsh et al. 2009; Pearce & Wyatt 2015; Yelverton et al. 2019; Friebe, Pearce & Löhne 2022; Sefilian, Rafikov & Wyatt 2023...

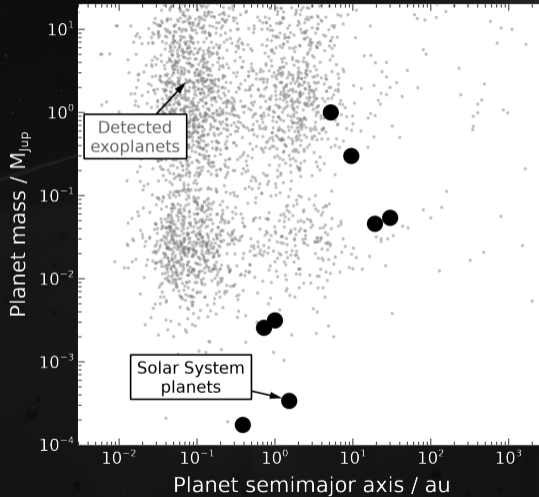
Do planets interact with extrasolar debris too?



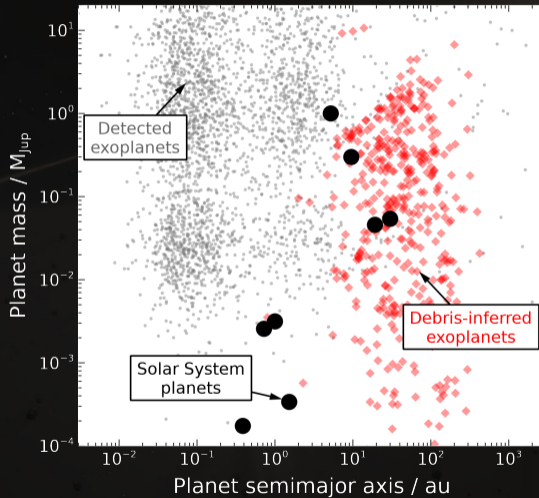
Debris discs as planetary probes



Debris discs as planetary probes



Debris discs as planetary probes



Aside: introduction to debris discs

Debris disks around main-sequence stars

Tim O. Nease*
*Department of Physics, University of Warwick, UK
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Abstract

Debris disks are collections of small bodies around stars, such as the Kuiper Belt and Zepher Belt in our Solar System. These disks are composed of debris resulting from collisions, including comets, asteroids, and dust grains. The Solar System debris disk consists of the Kuiper Belt, the asteroid belt, and the zodiacal dust cloud. Debris disks are also found around other stars. They are important for understanding the evolution of planetary systems and the formation of planets. This document provides an overview of debris disks, their structure, and their significance in the study of planetary systems.

Keywords: Debris disks, exoplanets, protoplanets, protoplanetary disks, planetary systems, debris disks, debris disks, debris disks, debris disks.

Contents	
1. Overview	1
2. Debris disks	2
3. Structure and formation	3
4. Observational evidence	4
5. Debris disks and exoplanets	5
6. Debris disks and the zodiacal cloud	6
7. Debris disks and the Kuiper Belt	7
8. Debris disks and the asteroid belt	8
9. Debris disks and the zodiacal dust cloud	9
10. Debris disks and the Kuiper Belt	10
11. Debris disks and the asteroid belt	11
12. Debris disks and the zodiacal dust cloud	12
13. Debris disks and the Kuiper Belt	13
14. Debris disks and the asteroid belt	14
15. Debris disks and the zodiacal dust cloud	15
16. Debris disks and the Kuiper Belt	16
17. Debris disks and the asteroid belt	17

Learning objectives

- By the end of this chapter, you should understand:
 - What a debris disk is.
 - How debris disks form.
 - How debris disks evolve.
 - How debris disks are observed.
 - How debris disks are related to exoplanets.
 - How debris disks are related to the zodiacal cloud.
 - How debris disks are related to the Kuiper Belt.
 - How debris disks are related to the asteroid belt.

2 Debris disks around main-sequence stars

Glossary

Asteroids are rocky objects that orbit the Sun in the inner Solar System. They are found primarily in the asteroid belt between Mars and Jupiter.

Comets are icy objects that orbit the Sun in the outer Solar System. They are found primarily in the Kuiper Belt and the Oort Cloud.

Debris disks are collections of small bodies around stars, such as the Kuiper Belt and Zepher Belt in our Solar System.

Exoplanets are planets that orbit stars other than our Sun.

Protoplanets are small bodies that are in the process of forming into planets.

Protoplanetary disks are disks of gas and dust that surround young stars.

Star formation is the process by which stars are born from clouds of gas and dust.

Zodiacal cloud is a cloud of dust grains that surrounds the Sun.

Zodiacal dust is the dust that makes up the zodiacal cloud.

Zodiacal light is the light that is scattered by the zodiacal dust.

Zodiacal dust is the dust that makes up the zodiacal cloud.

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4 Debris disks around main-sequence stars

Exoplanets and debris disks

Exoplanets are planets that orbit stars other than our Sun. They are found around other stars in our galaxy and beyond.

Debris disks are collections of small bodies around stars, such as the Kuiper Belt and Zepher Belt in our Solar System.

Exoplanets and debris disks are related to each other in several ways.

Exoplanets can form from debris disks.

Debris disks can be found around exoplanets.

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Debris disks around main-sequence stars

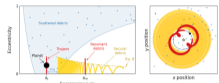


Fig. 18 Diagram illustrating the typical grain-grain collision frequency in the Kuiper Belt. The left panel shows a cross-section of the Kuiper Belt with a grain and a planet. The right panel shows a top-down view of a grain and a planet. The diagram includes labels for 'Kuiper Belt', 'Planet', 'Grain', and 'Collision frequency'.

$$\tau_{coll} = \frac{1}{n \sigma v} \quad (1)$$

where n is the number density of grains, σ is the collision cross-section, and v is the relative velocity. The collision cross-section is given by $\sigma = \pi a^2$, where a is the grain radius.

The collision frequency is given by $\nu_{coll} = n \sigma v$. The collision frequency is given by $\nu_{coll} = n \sigma v$.

$$\nu_{coll} = n \sigma v \quad (2)$$

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$$\nu_{coll} = n \sigma v \quad (3)$$

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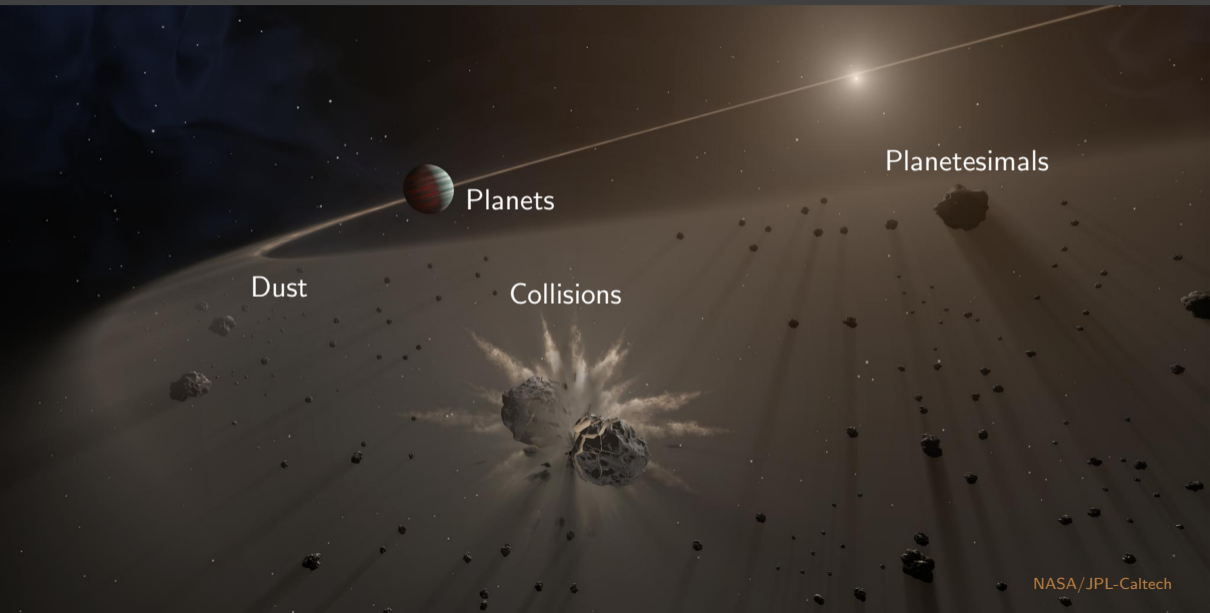
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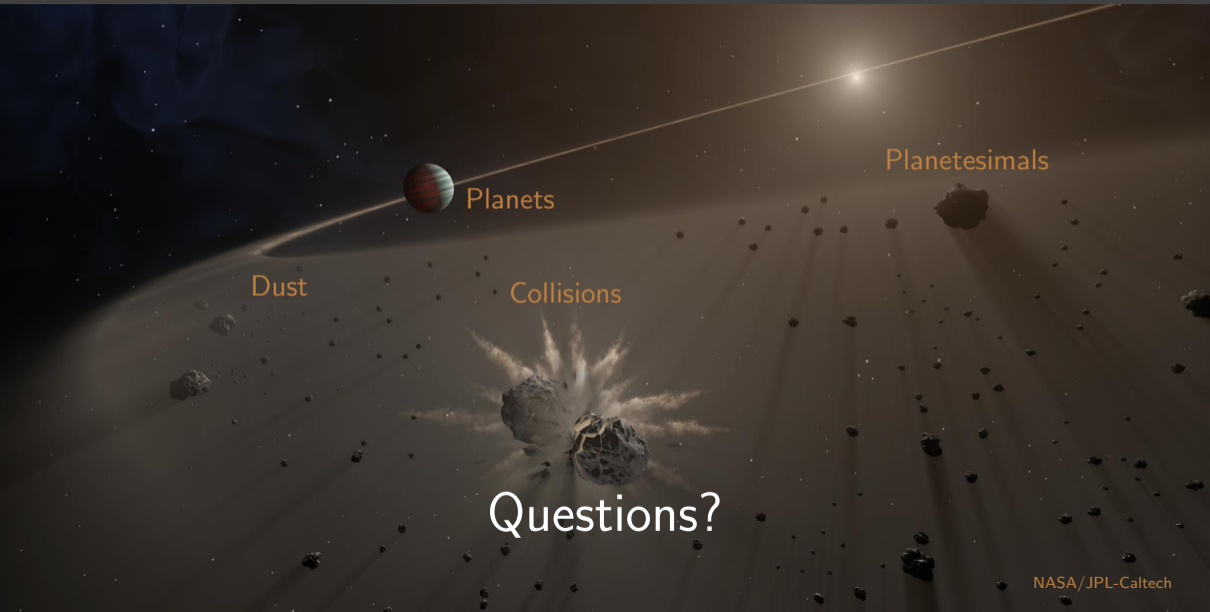
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Conclusions



Conclusions



Planets

Planetesimals

Dust

Collisions

Questions?

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