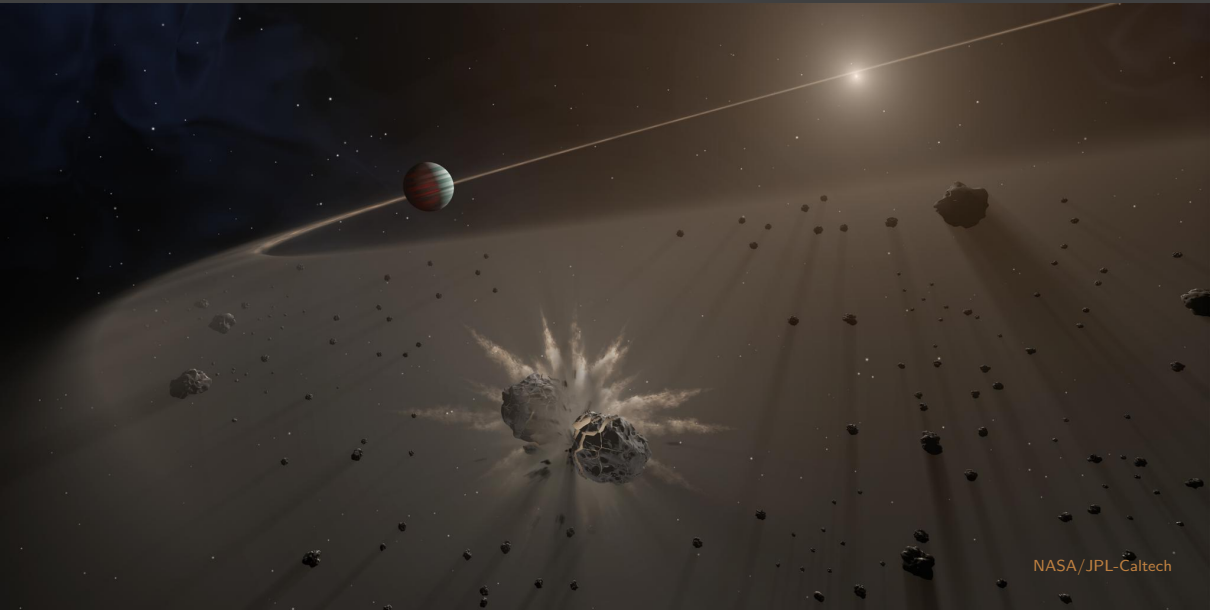
Debris-disc dynamics

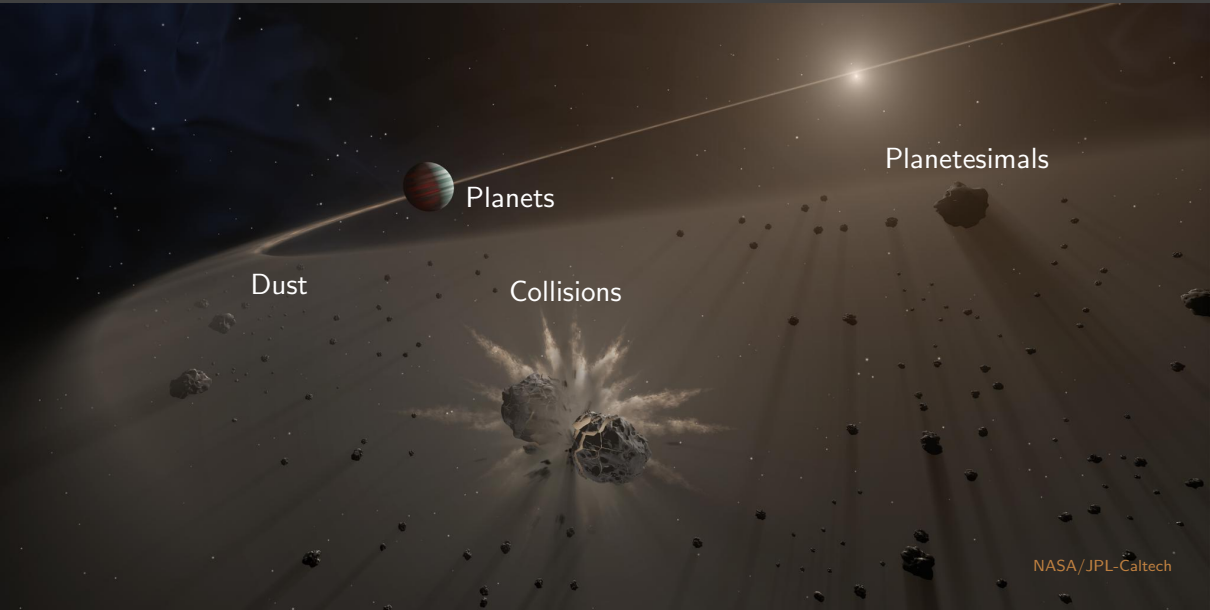
Tim D. Pearce

Image: NASA/JPL-Caltech

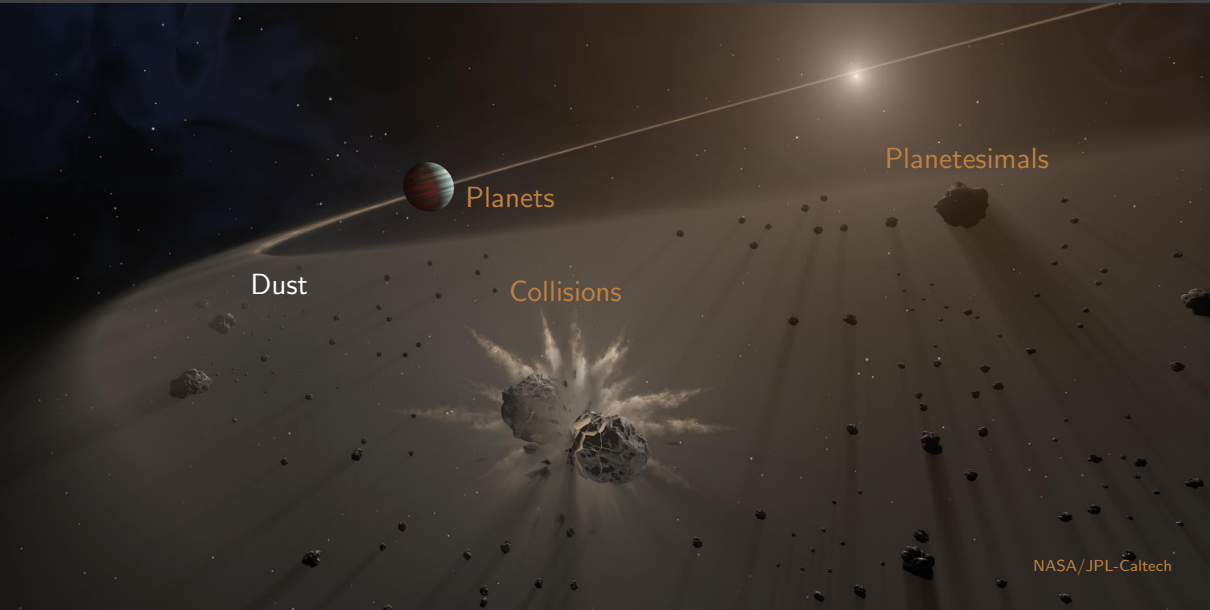
Debris-disc dynamics



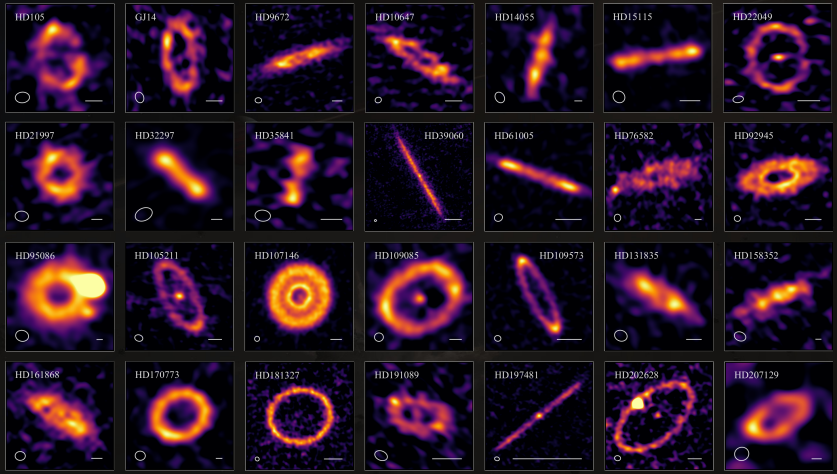
Debris-disc dynamics



Debris-disc dynamics

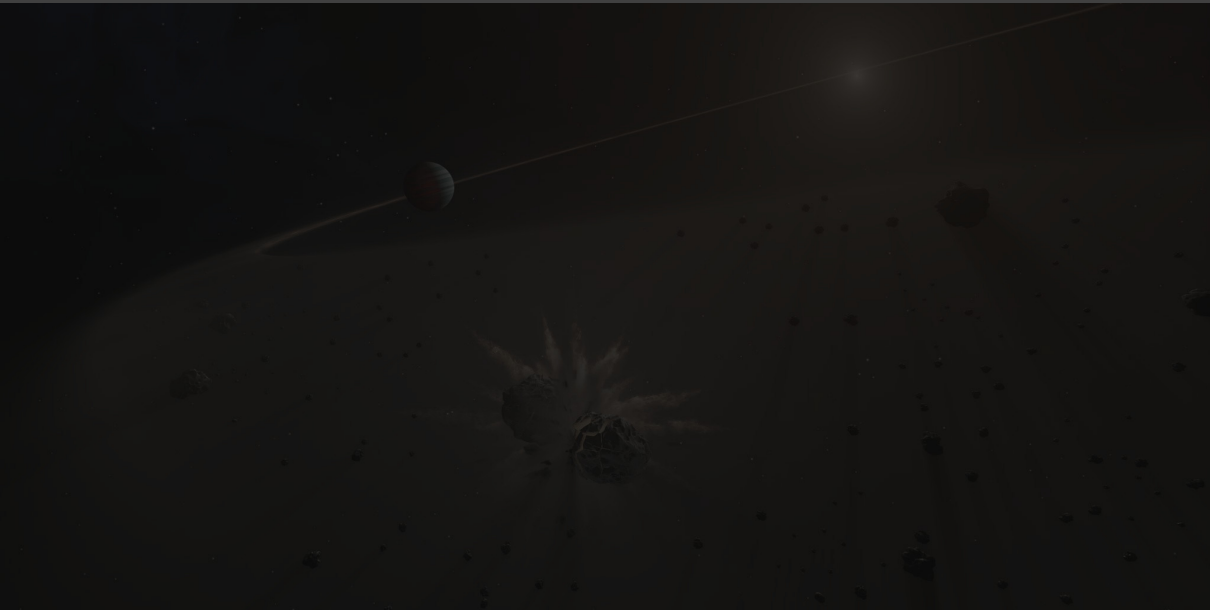


We see dust

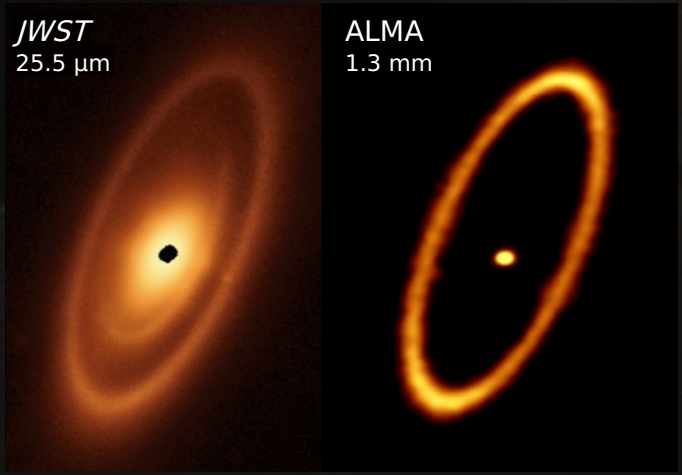


Matrà et al. in prep.

Observed grains have size similar to the observing wavelength

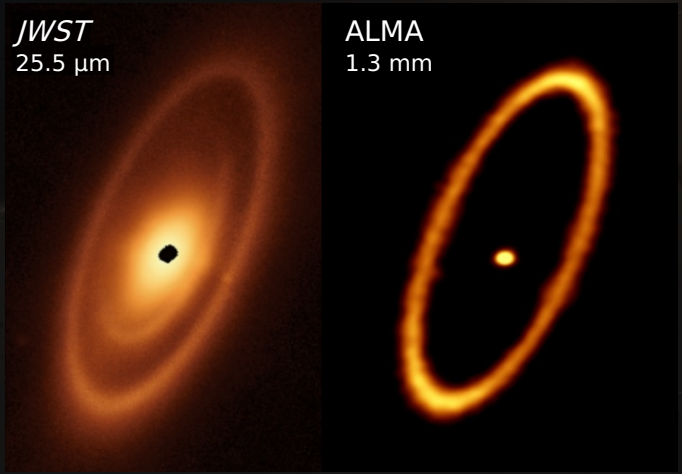


Observed grains have size similar to the observing wavelength



Gáspár et al. 2023; MacGregor et al. 2017

Observed grains have size similar to the observing wavelength

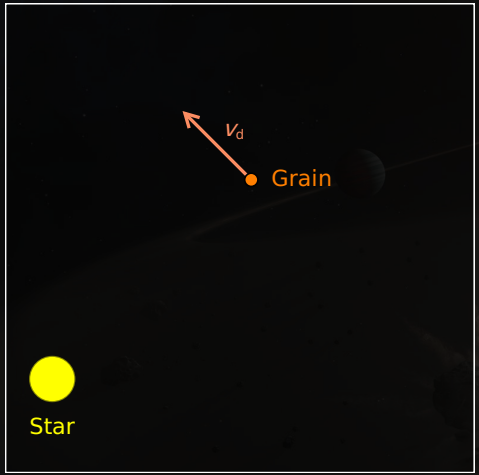


$\Rightarrow$ Debris discs look different at different grain sizes

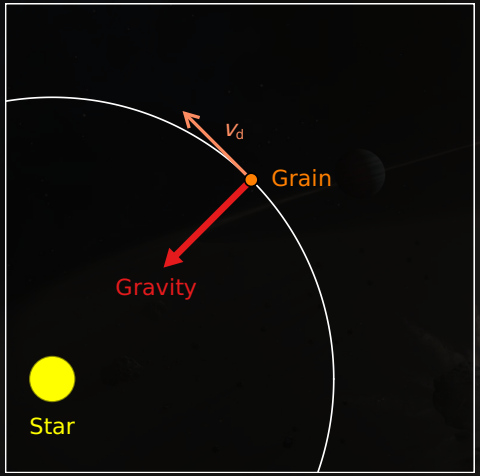
Gáspár et al. 2023; MacGregor et al. 2017

Forces on dust grains

Forces on dust grains



Forces on dust grains

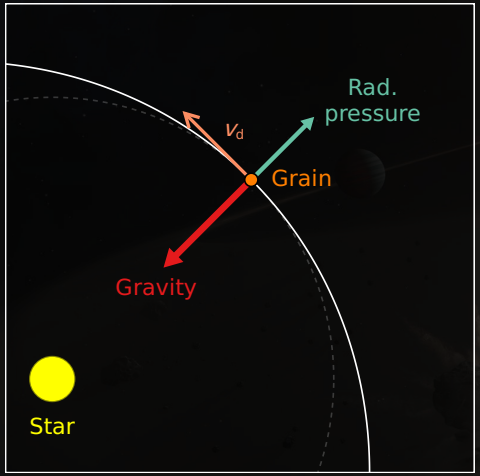


Forces:

- Gravity

$$\mathbf{F}_{\mathrm{grav}} = -\frac{GM_* m_\mathrm{d}}{r^2}\hat{\mathbf{r}}$$

Forces on dust grains

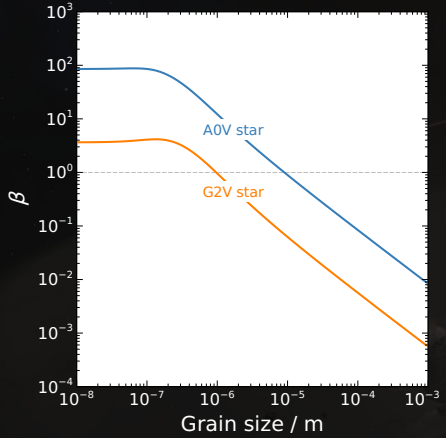


Forces:

- Gravity
- Radiation pressure

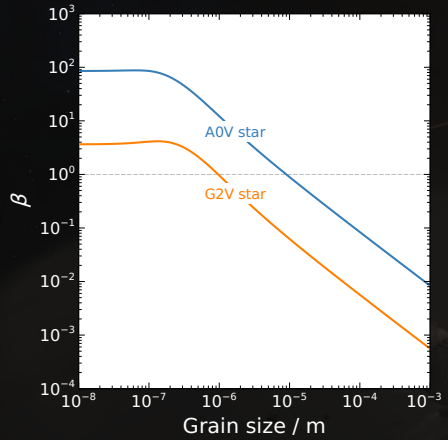
$$\mathbf{F} = \underbrace{\mathbf{F}_{\mathrm{grav}}(1-\beta)}_{\text{Gravity + rad. pressure}}$$

Forces on dust grains



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

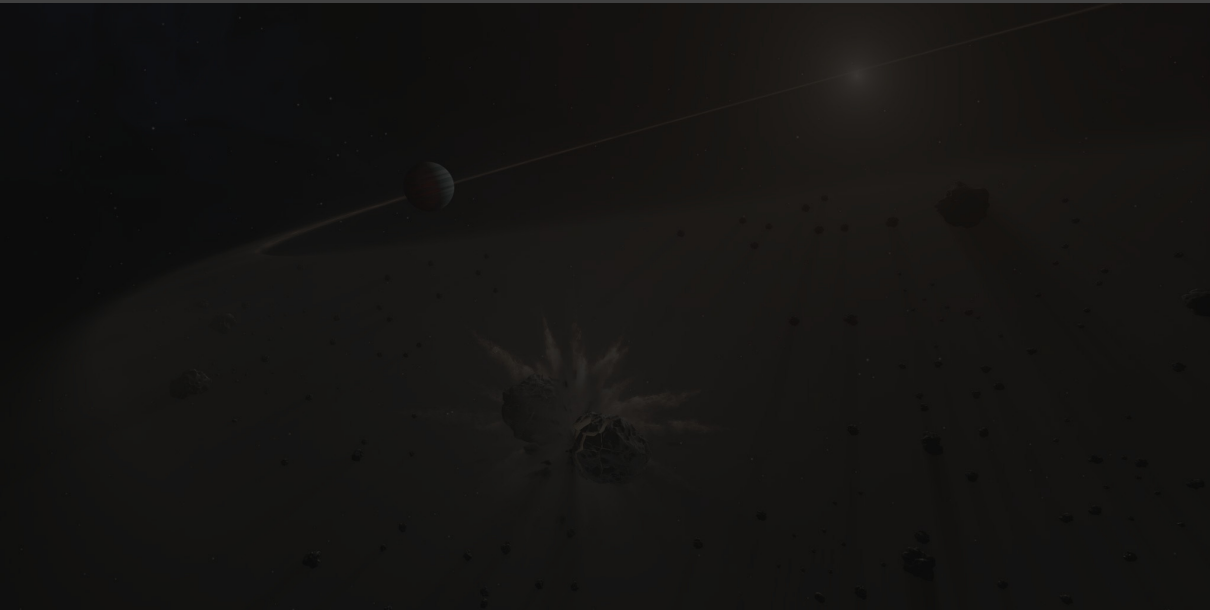
Forces on dust grains



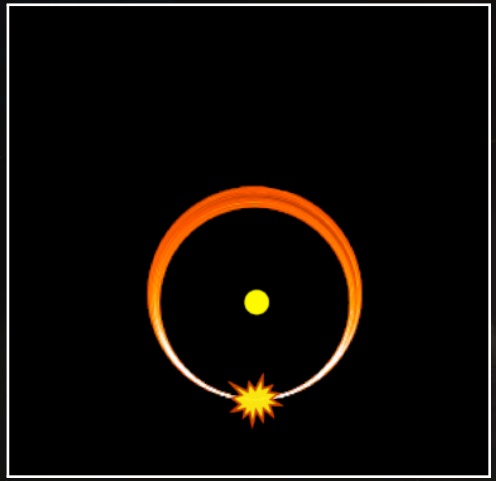
- Smaller grains: higher β
- Brighter stars: higher β

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

Small grains have more-extended distributions



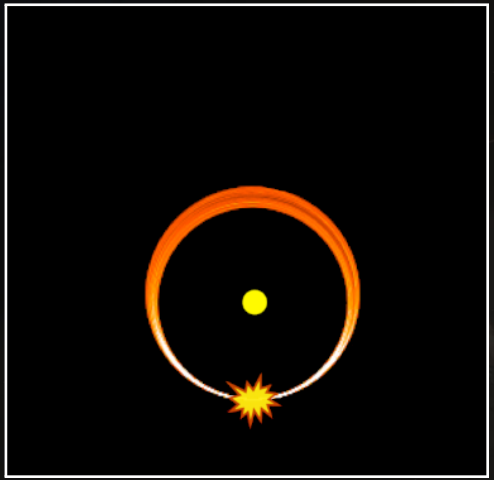
Small grains have more-extended distributions



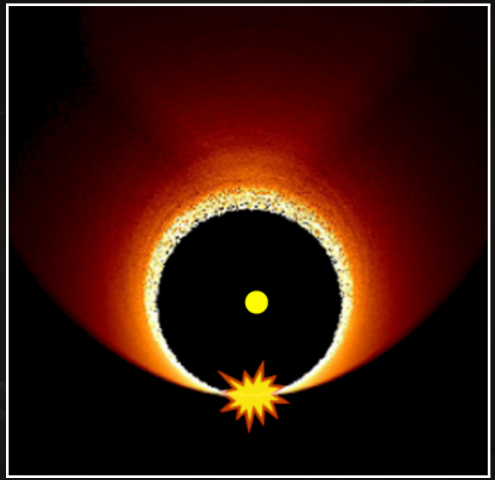
Large grains

Jones et al. 2023

Small grains have more-extended distributions



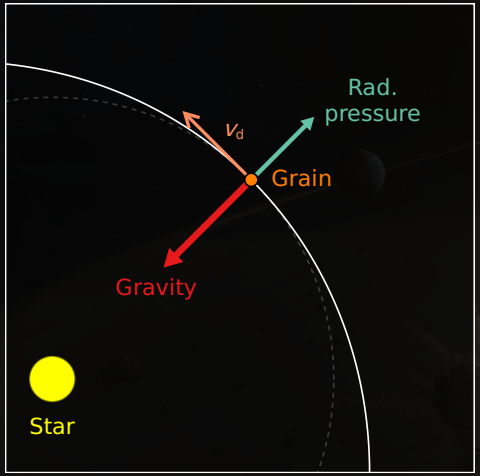
Large grains



Small grains

Jones et al. 2023

Forces on dust grains

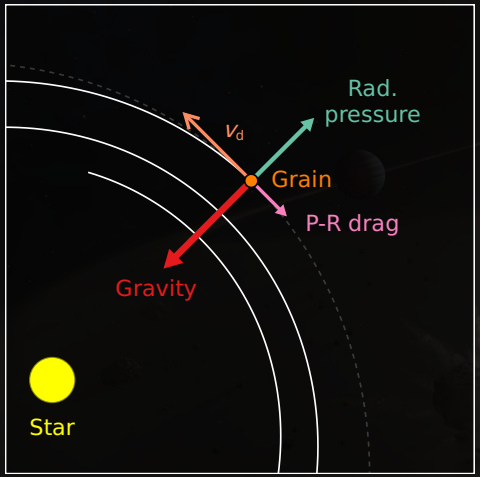


Forces:

- Gravity
- Radiation pressure

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

Forces on dust grains

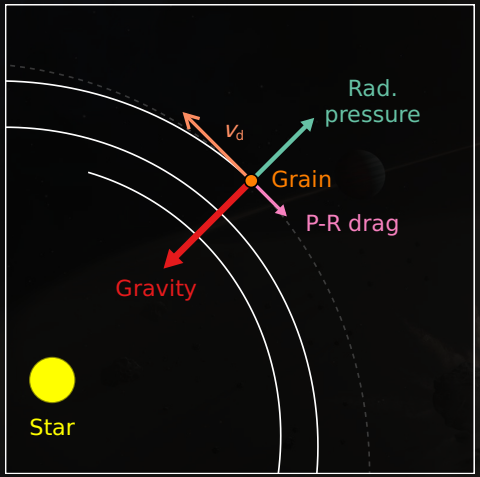


Forces:

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

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

Forces on dust grains

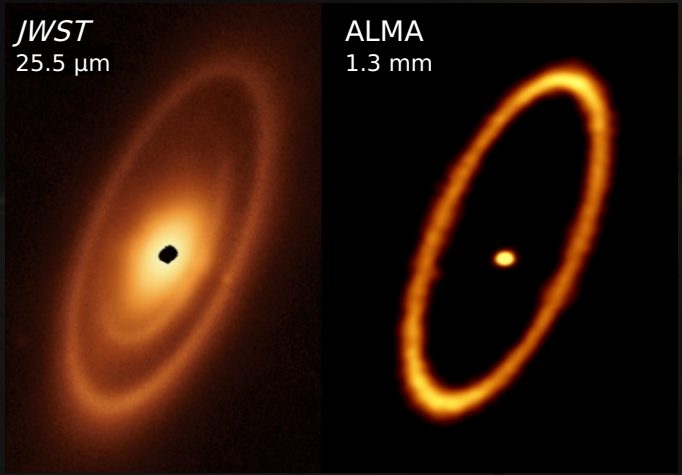


Forces:

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

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

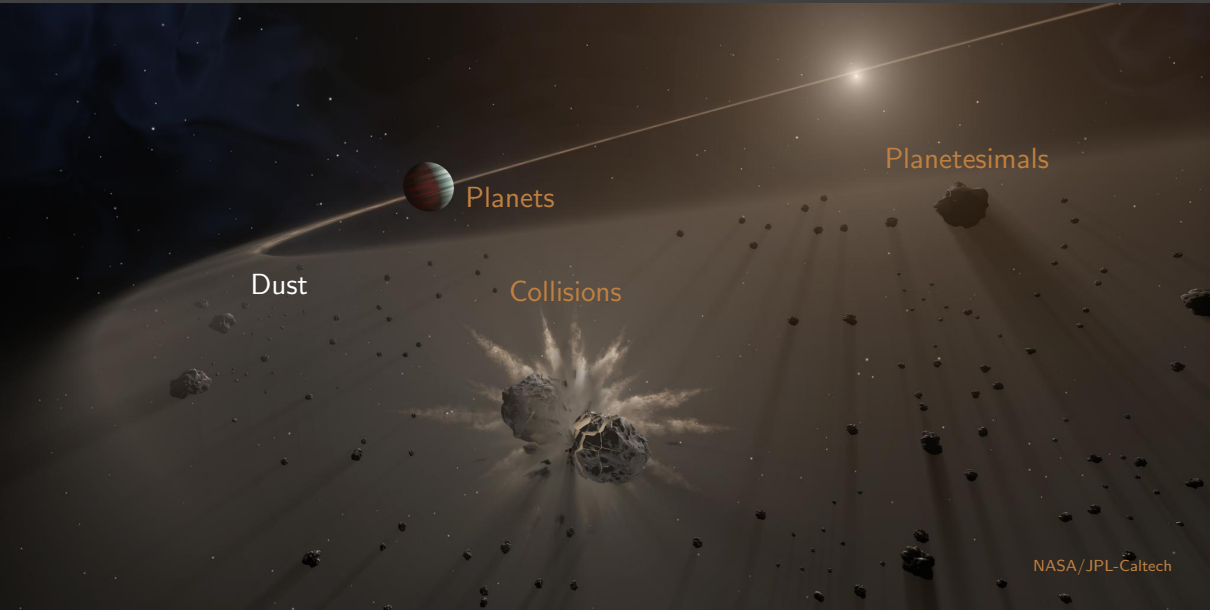
Small grains have more-extended distributions

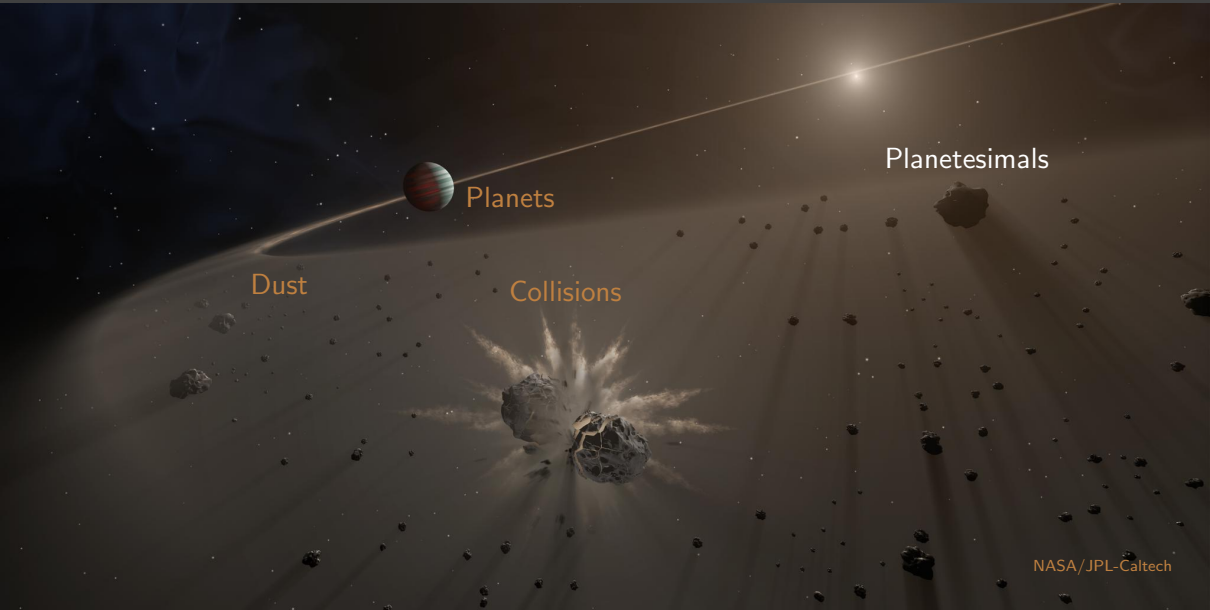


Gáspár et al. 2023; MacGregor et al. 2017

But dust should only survive for $\sim$ 1 Myr.

So where does the dust come from?


Planetesimals
Planets
Dust
Collisions
NASA/JPL-Caltech


Planetesimals
Planets
Dust
Collisions
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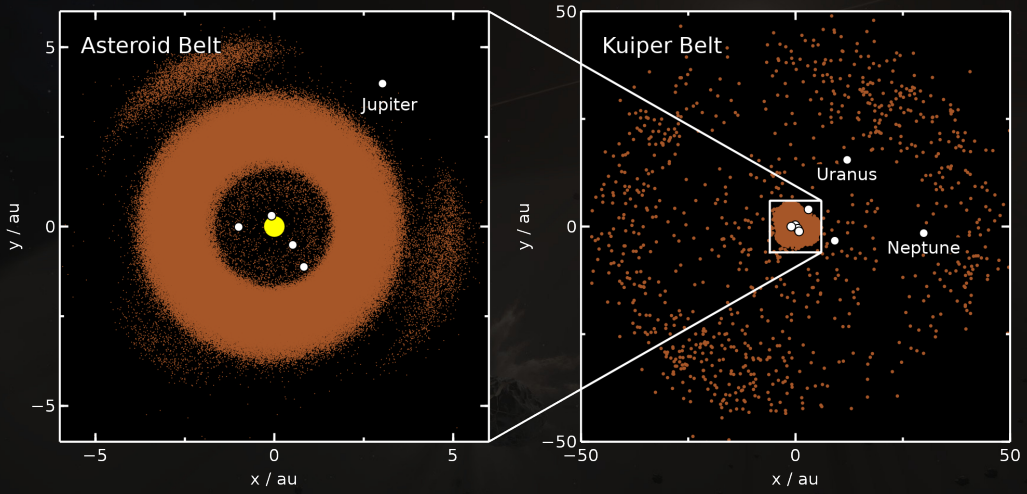
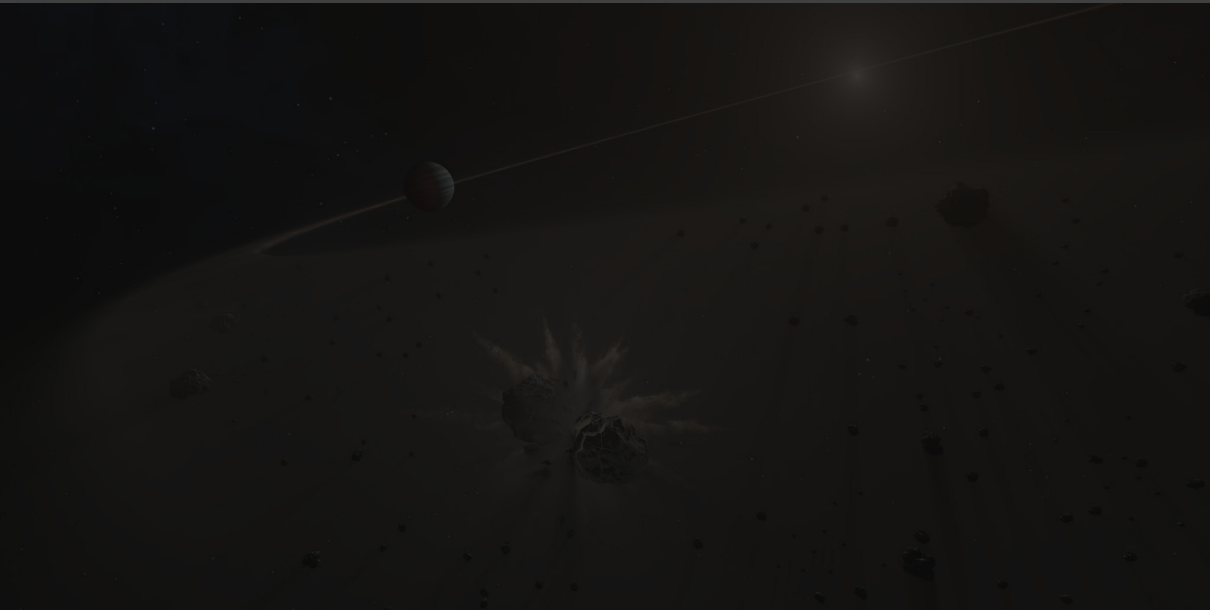
Planetesimals in the Solar System



Ephemerides: JPL

But we cannot see extrasolar planetesimals



But we cannot see extrasolar planetesimals

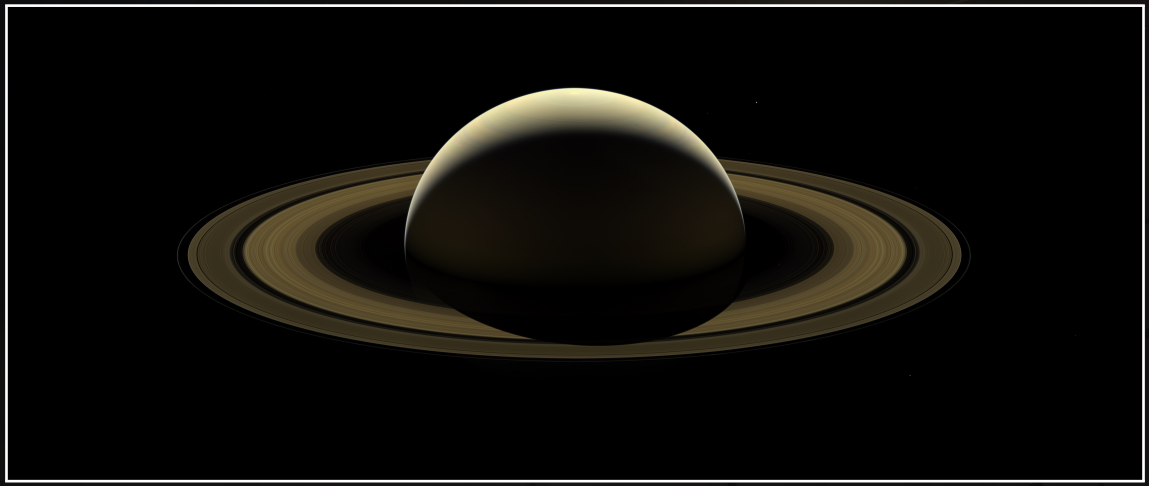


Image: NASA/JPL-Caltech/Space Science Institute

But we cannot see extrasolar planetesimals

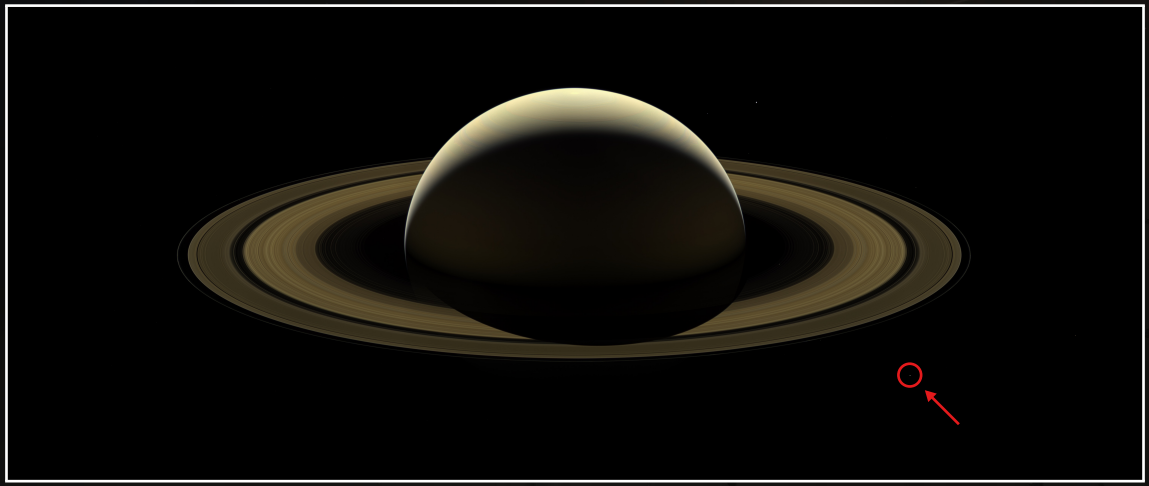
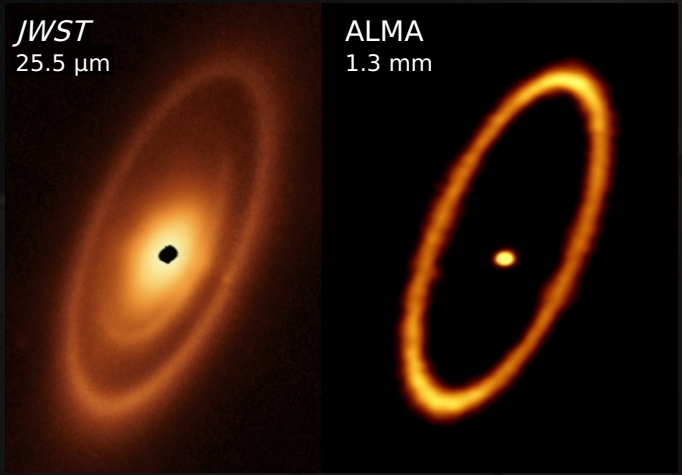
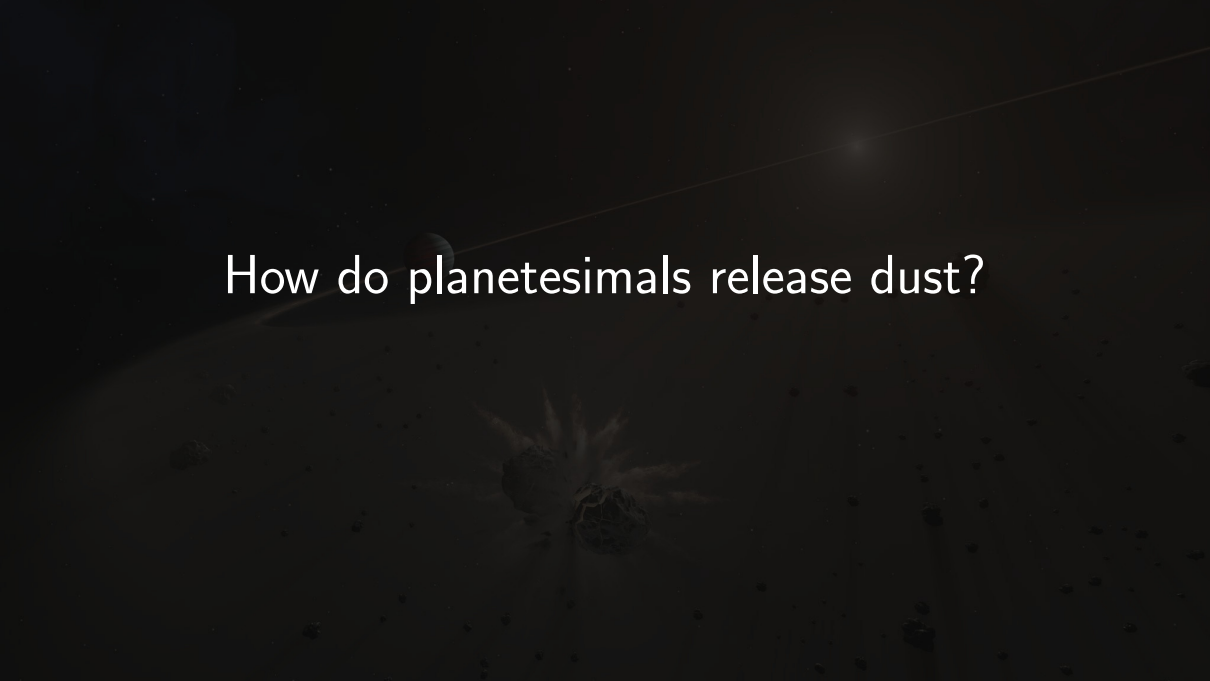


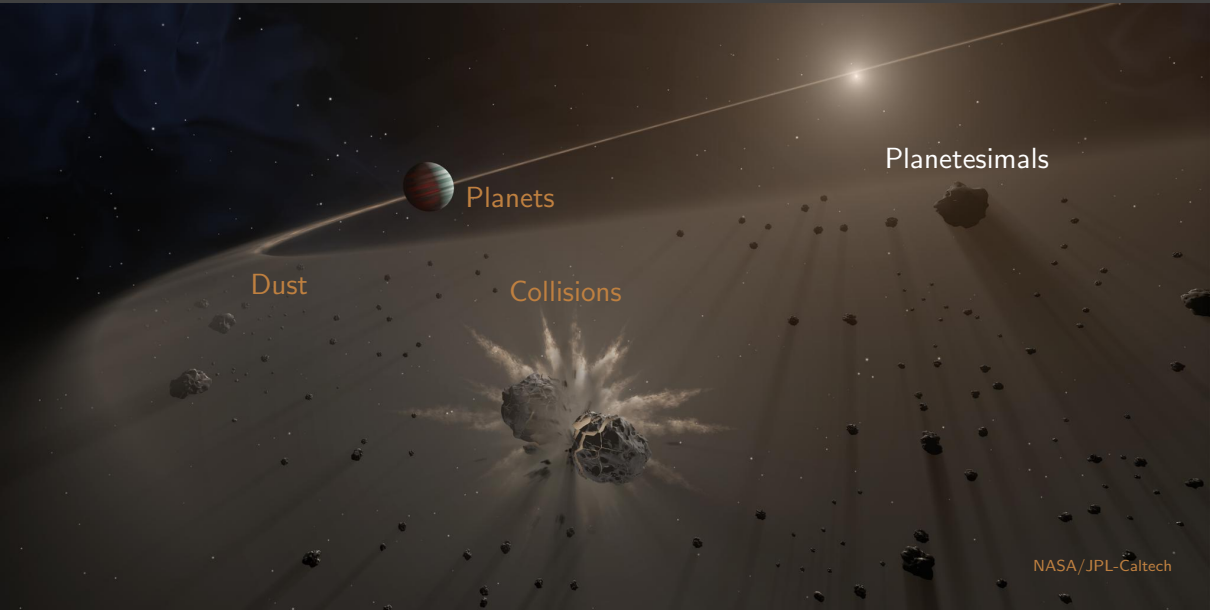
Image: NASA/JPL-Caltech/Space Science Institute

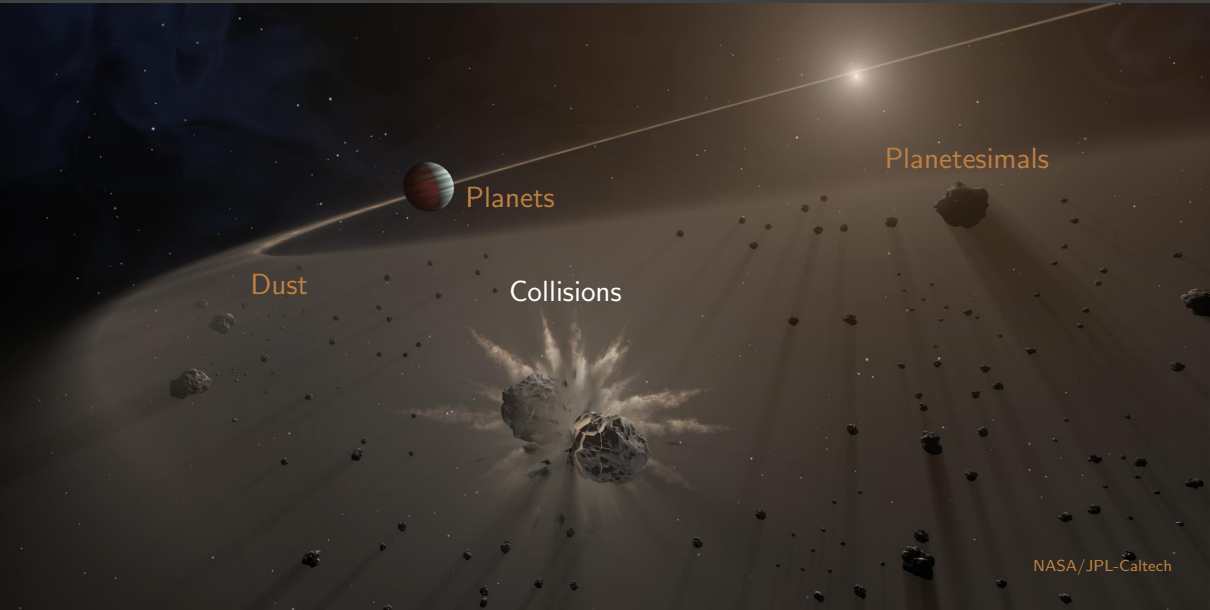
Large grains trace planetesimals



Gáspár et al. 2023; MacGregor et al. 2017


How do planetesimals release dust?


Planetesimals
Planets
Dust
Collisions
NASA/JPL-Caltech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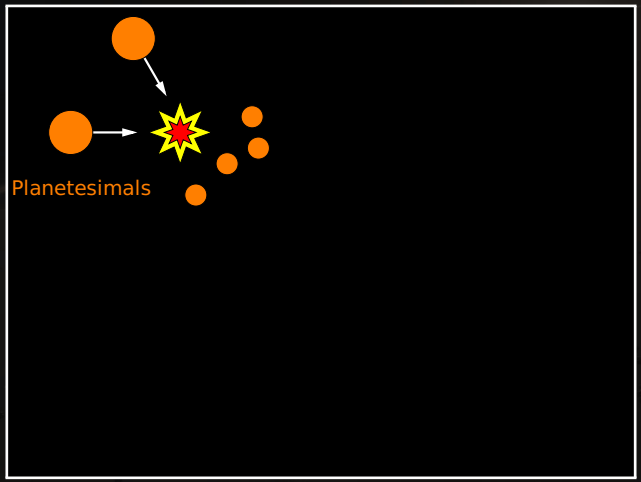
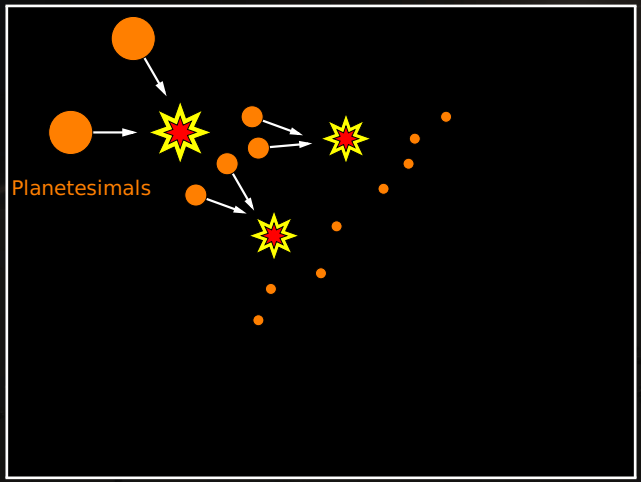
Collisional cascade

Collisional cascade

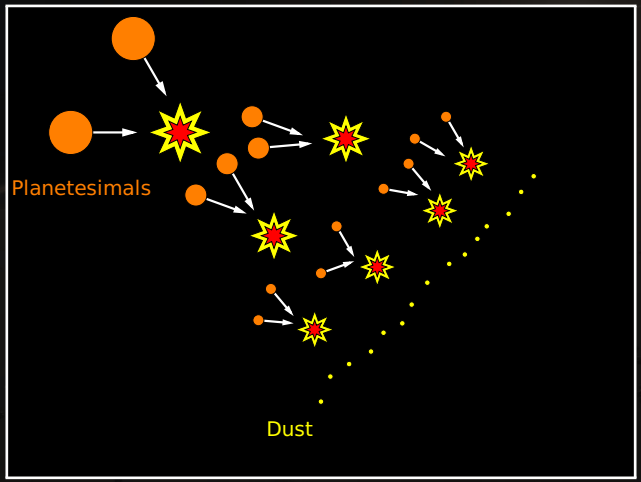
Collisional cascade



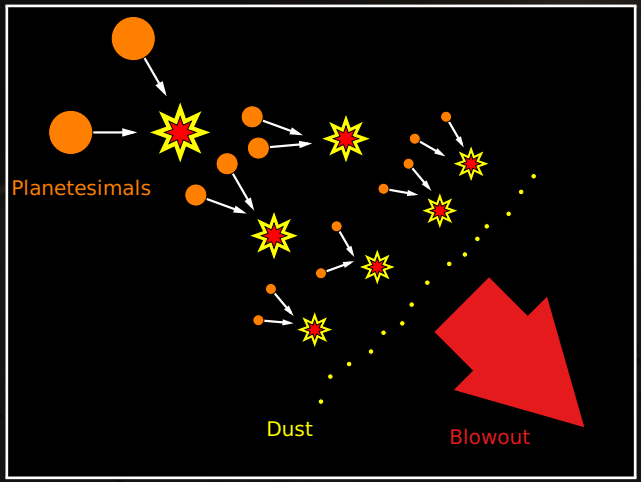
Collisional cascade



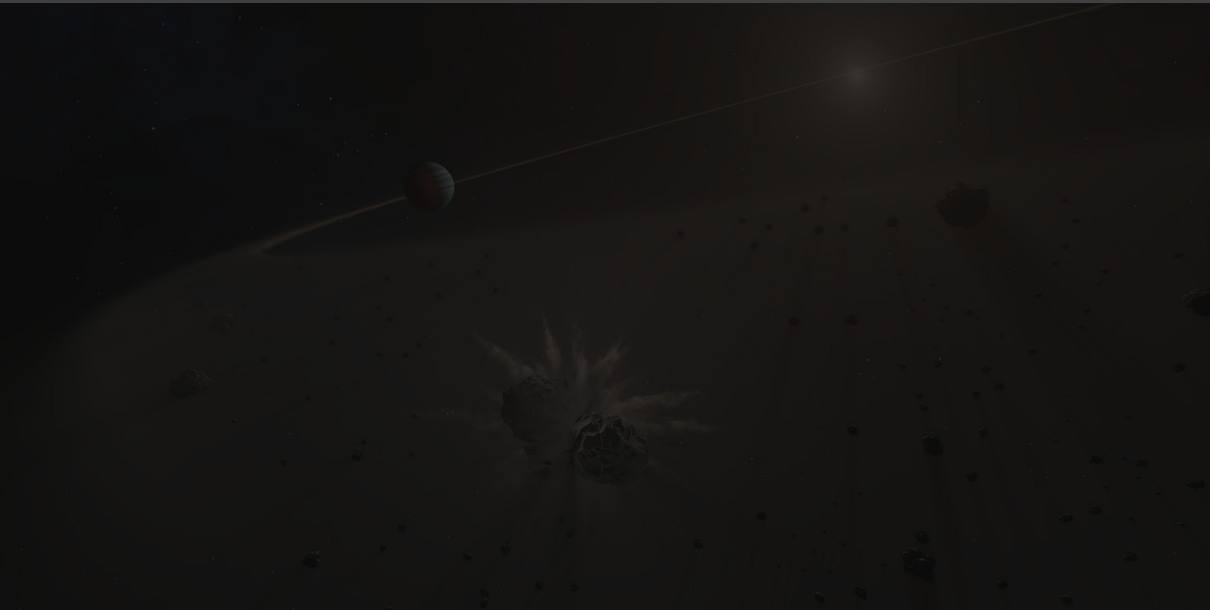
Collisional cascade



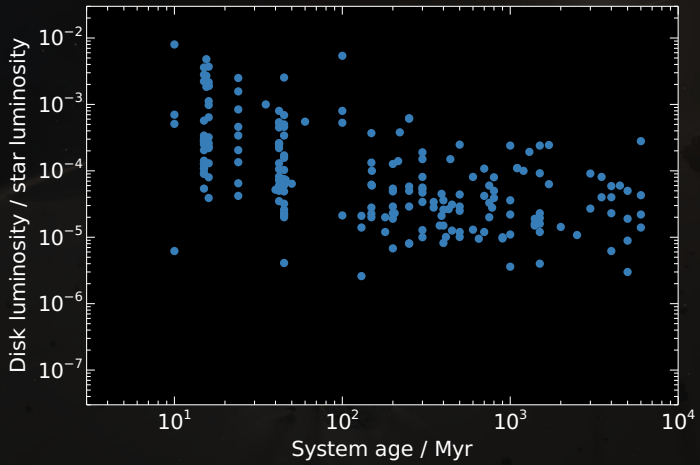
Collisional cascade



Debris discs lose mass and get fainter over time

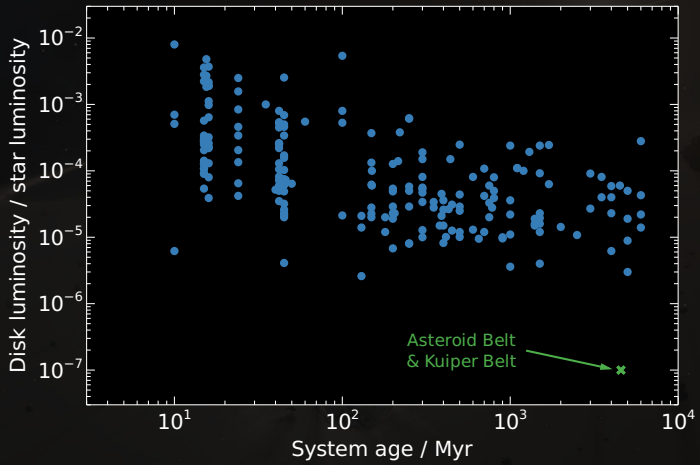


Debris discs lose mass and get fainter over time



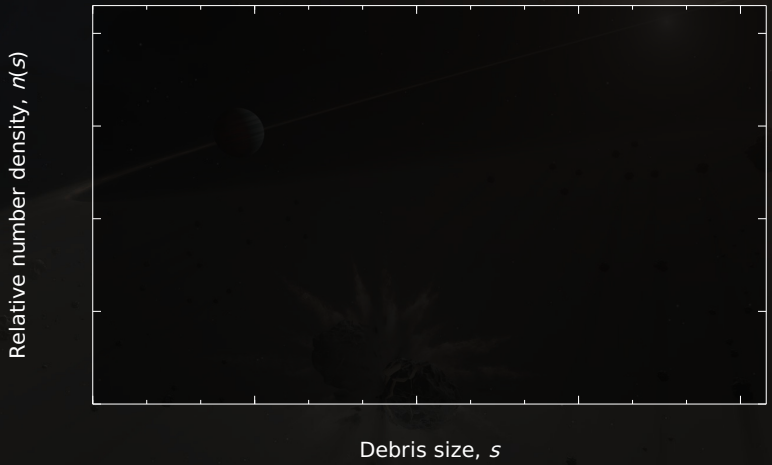
Pearce 2024

Debris discs lose mass and get fainter over time

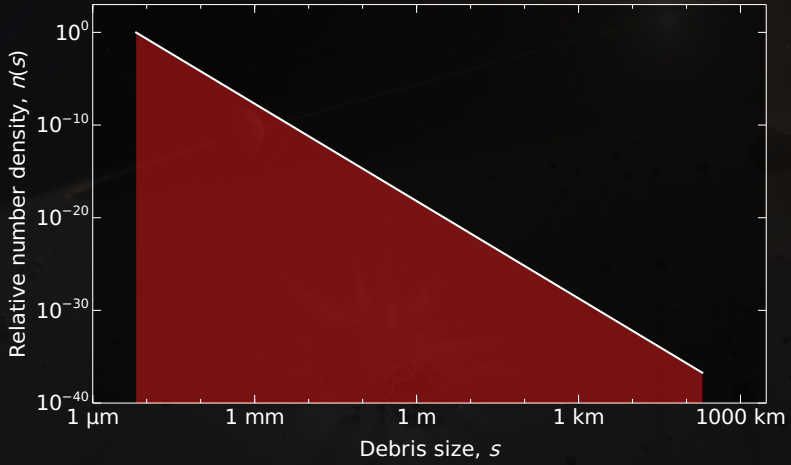


Pearce 2024

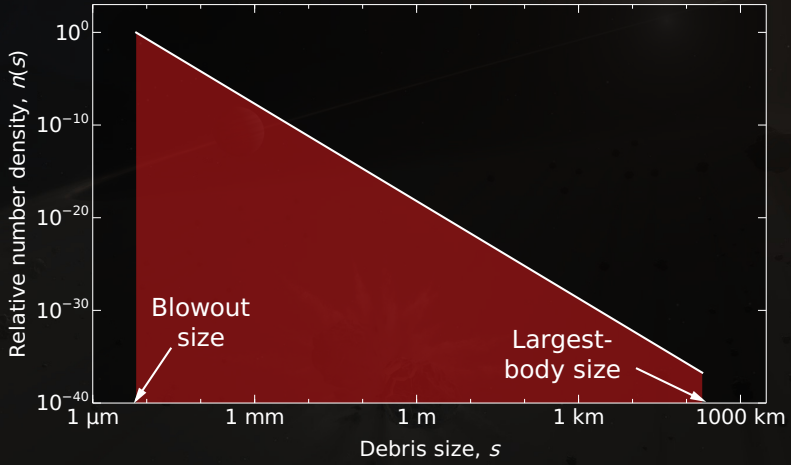
Size distribution



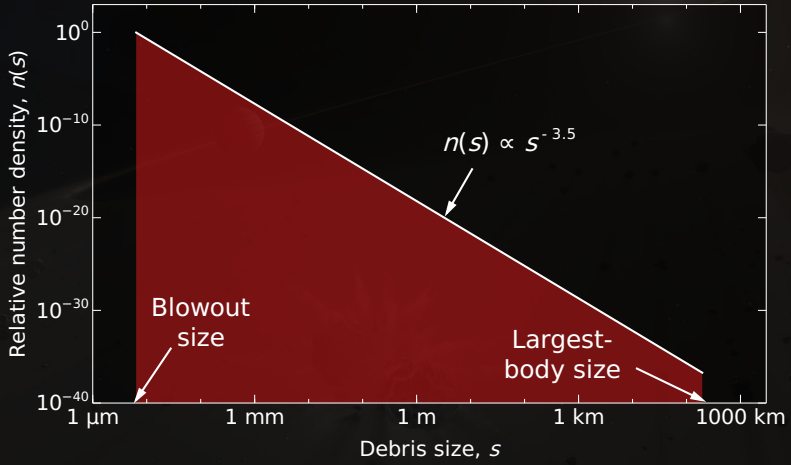
Size distribution



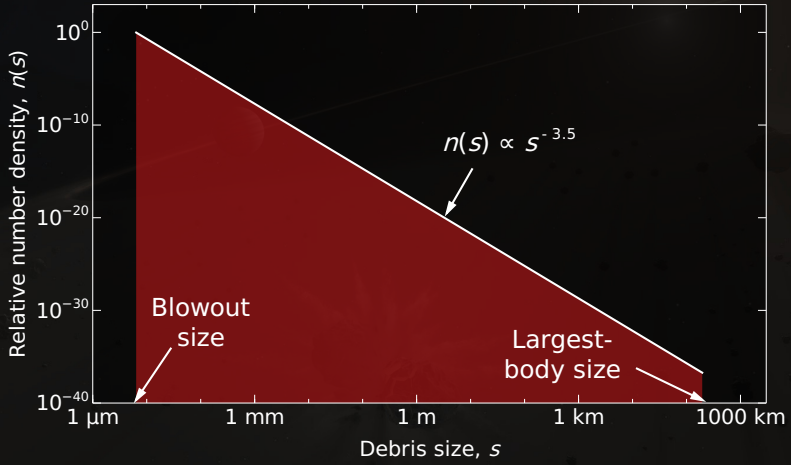
Size distribution



Size distribution

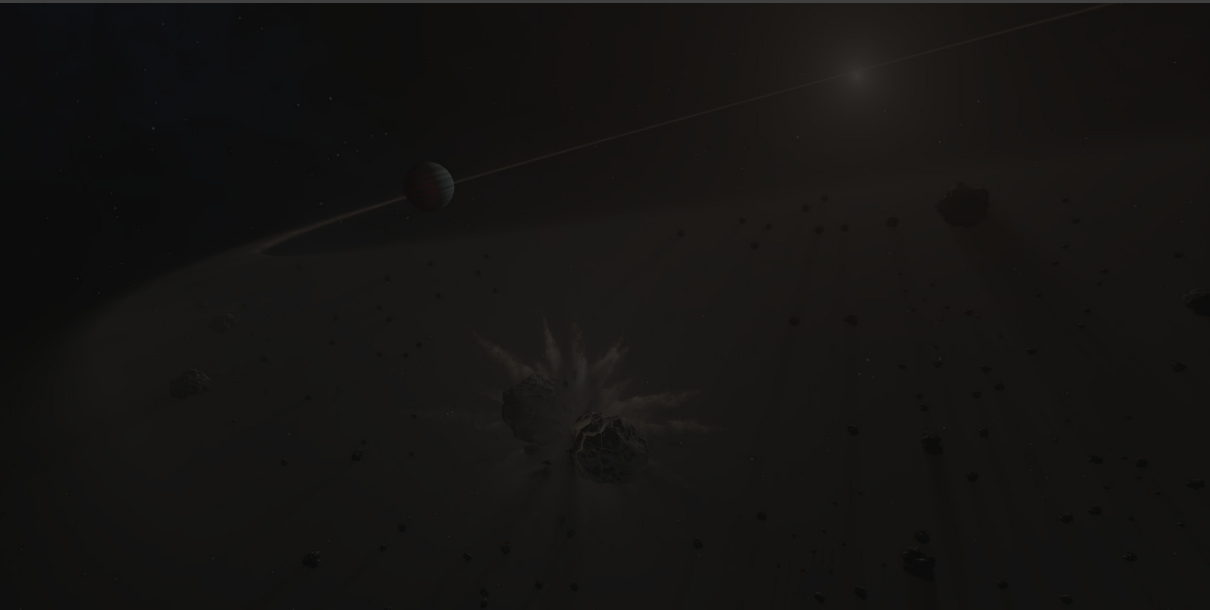


Size distribution



$\Rightarrow$ Smallest bodies dominate emission, largest dominate mass

Stirring



Stirring

Stirring

Stirring mechanisms:

- Self stirring

Stirring

Stirring mechanisms:

- Self stirring
- Flyby stirring

Stirring

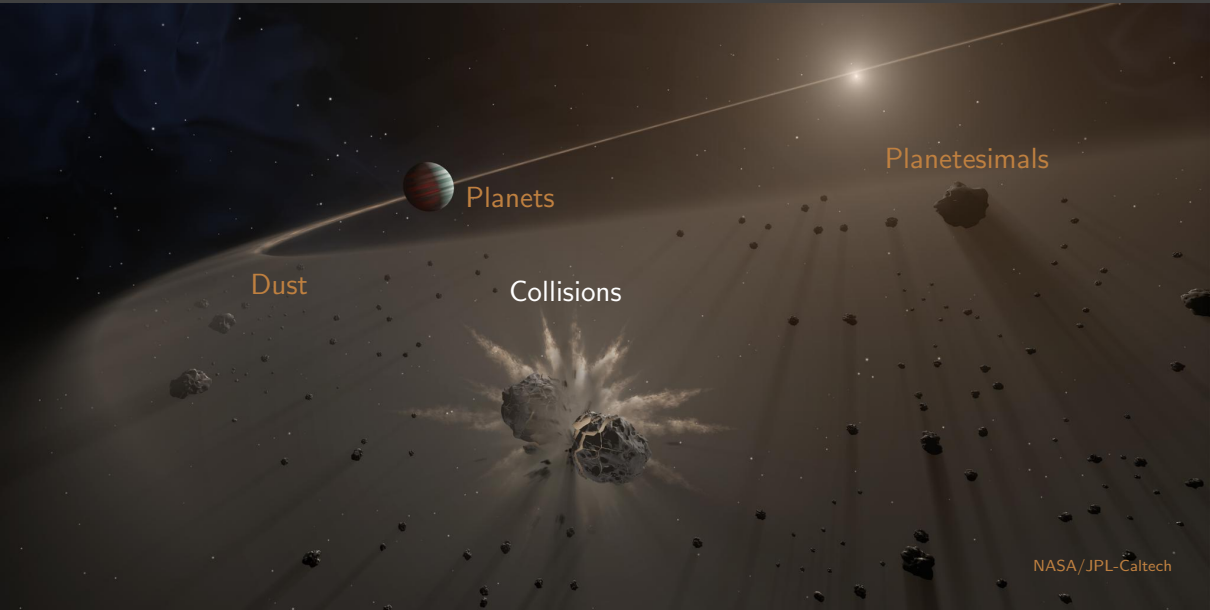
Stirring mechanisms:

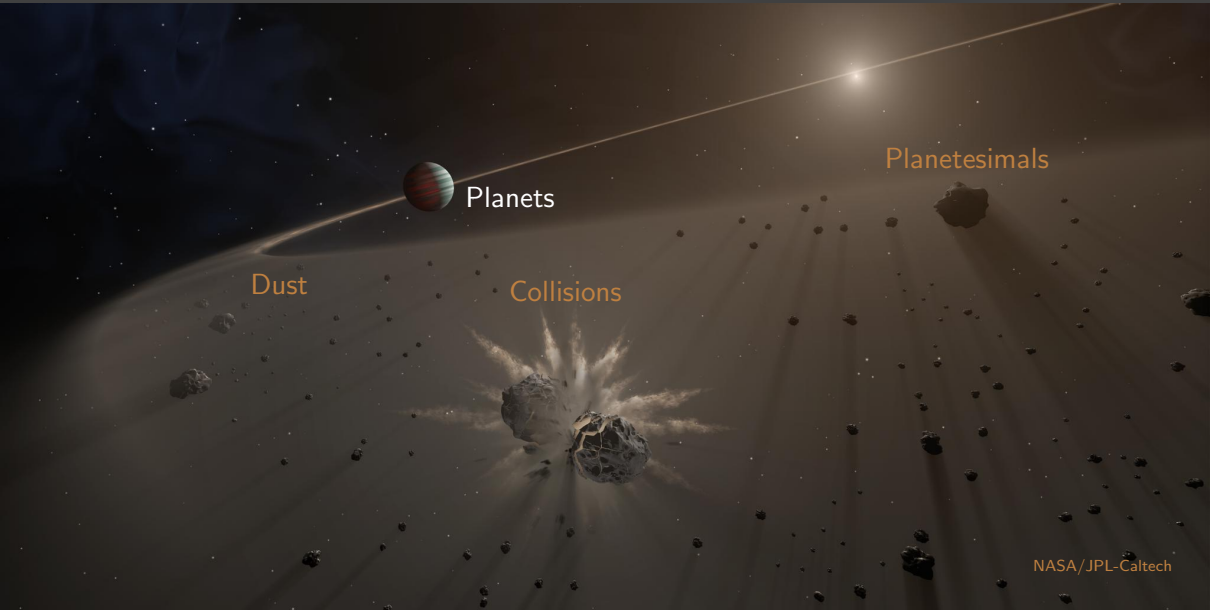
- Self stirring
- Flyby stirring
- Pre stirring

Stirring

Stirring mechanisms:

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


Planetesimals
Planets
Dust
Collisions
NASA/JPL-Caltech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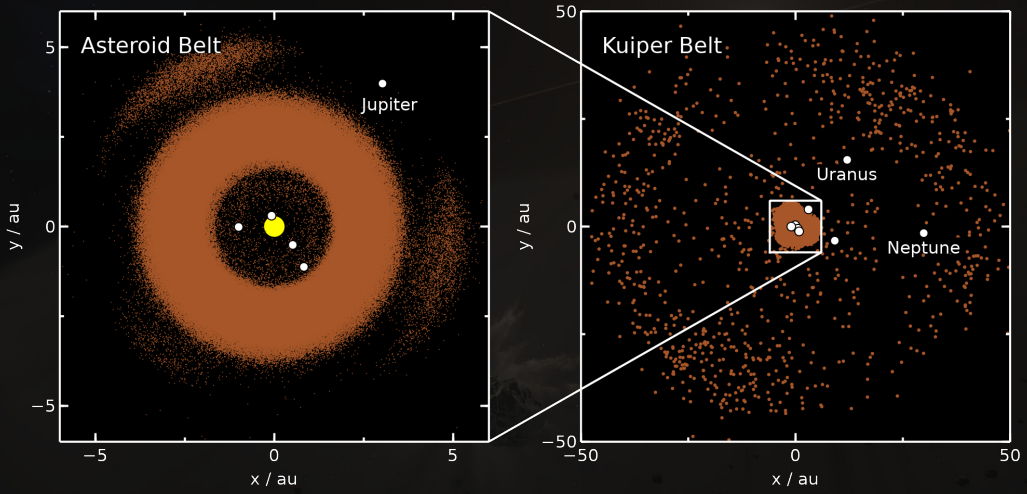
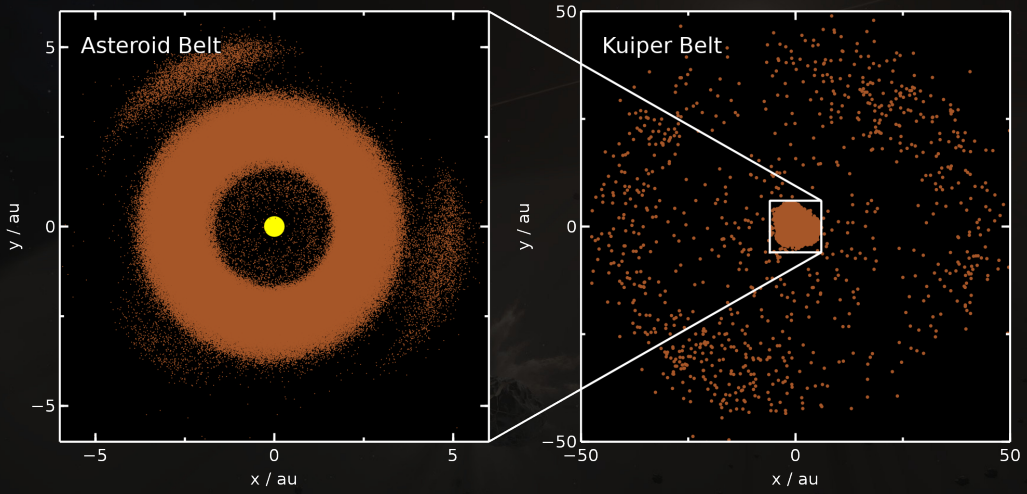
Planets and debris interact in the Solar System



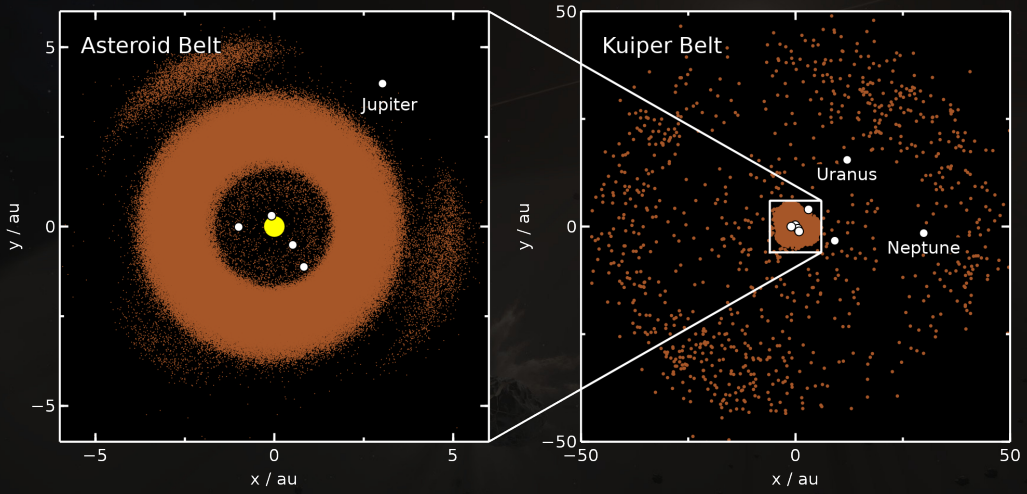
Ephemerides: JPL

Planets and debris interact in the Solar System



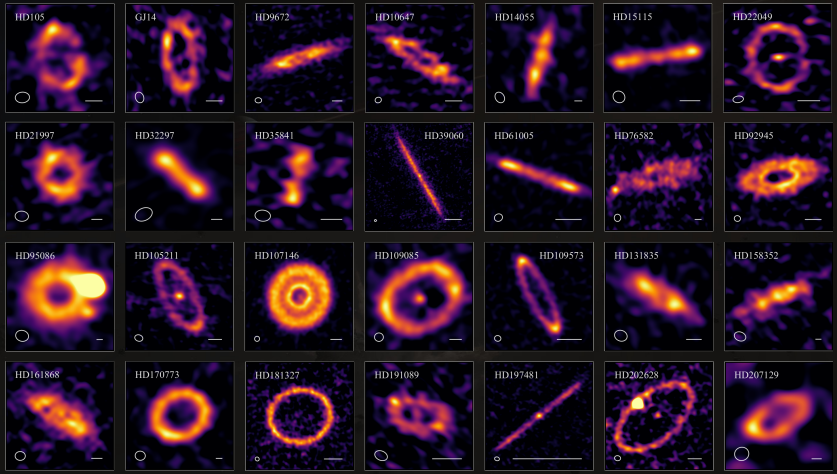
Ephemerides: JPL

Planets and debris interact in the Solar System

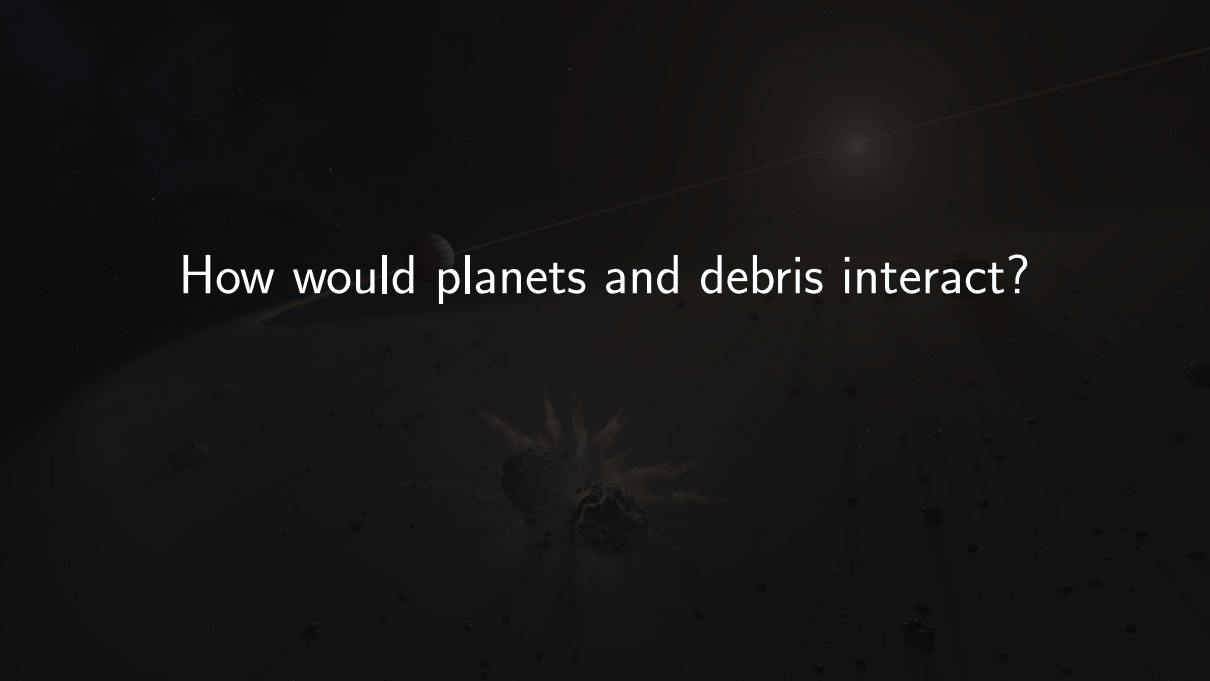


Ephemerides: JPL

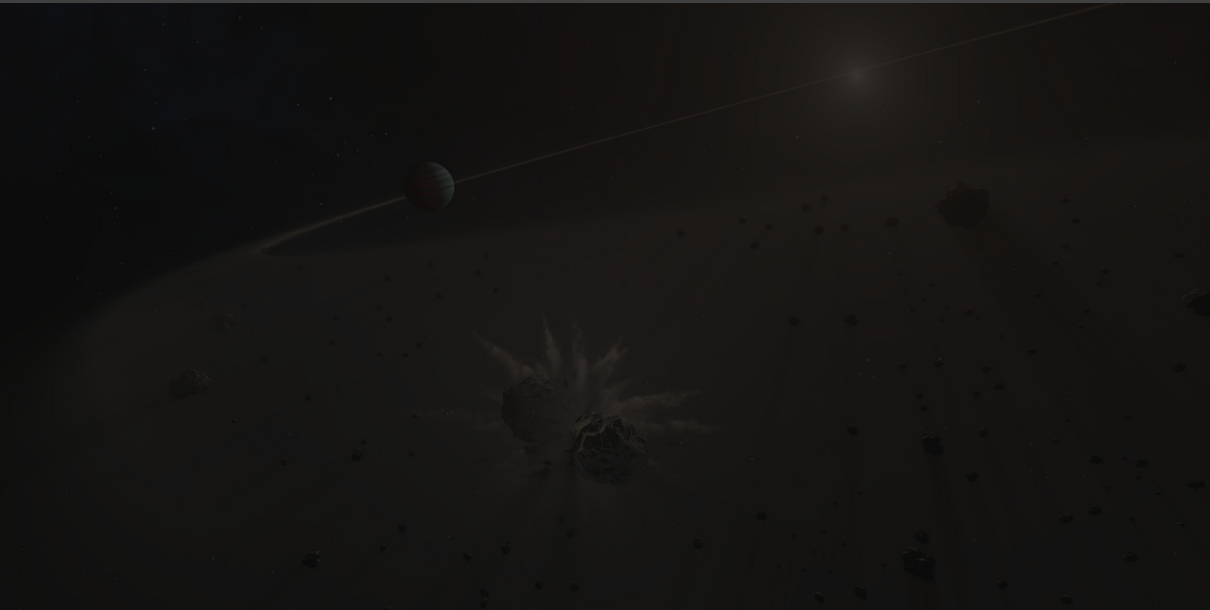
Do planets interact with extrasolar debris too?



Matrà et al. in prep.


How would planets and debris interact?

1. Planets can scatter nearby debris



1. Planets can scatter nearby debris

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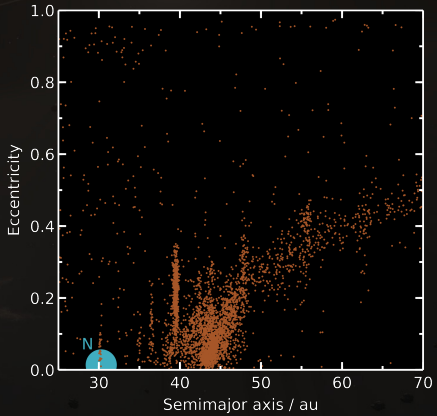
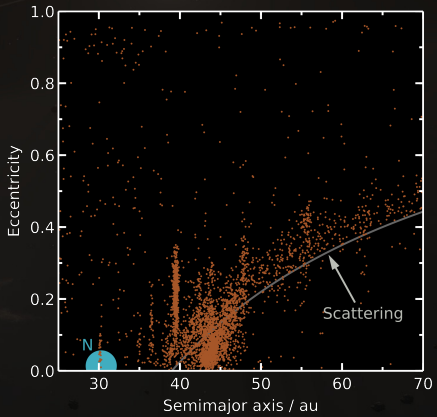
Kuiper Belt



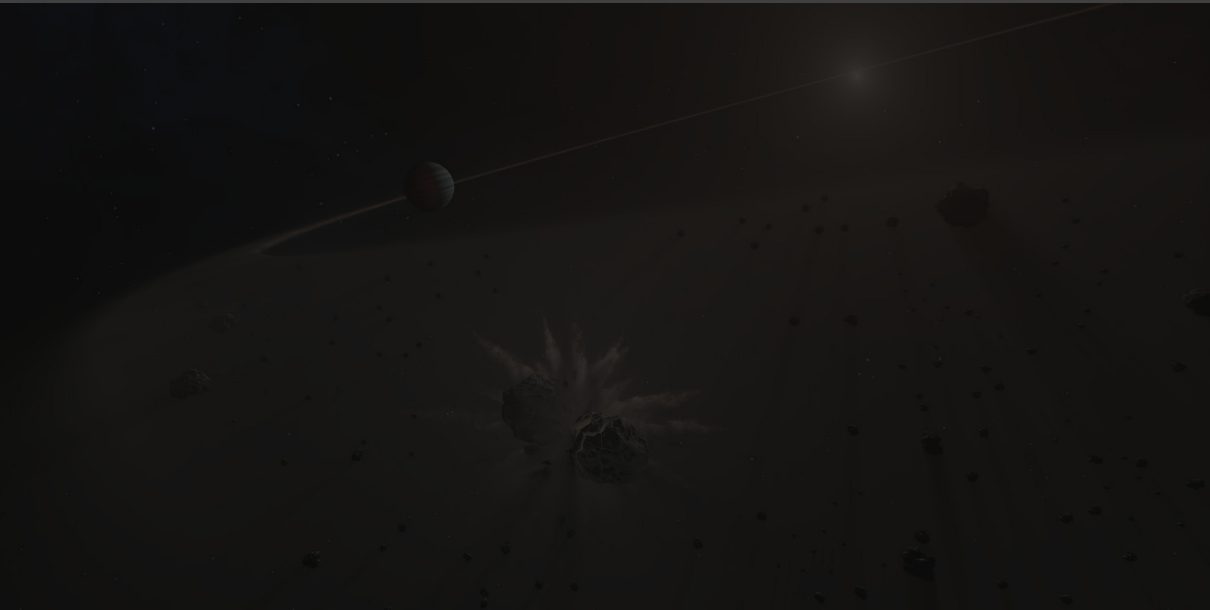
Ephemerides: JPL

1. Planets can scatter nearby debris



Ephemerides: JPL

2. Planets can make discs eccentric



2. Planets can make discs eccentric

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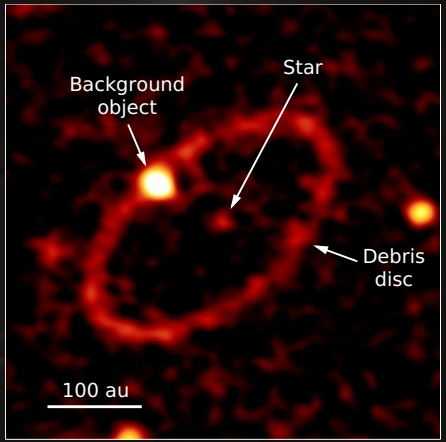
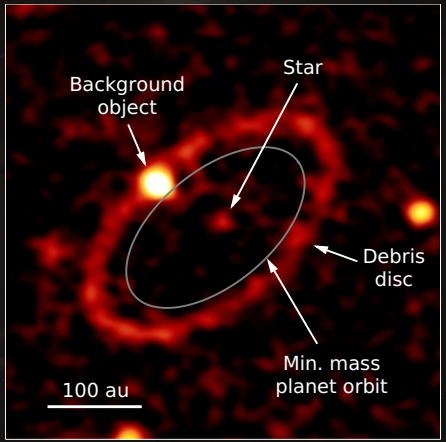


ALMA: Faramaz et al. 2019

2. Planets can make discs eccentric



ALMA: Faramaz et al. 2019

Planet parameters: Pearce et al. 2022

3. Planets can warp discs

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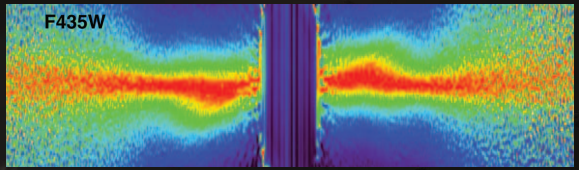
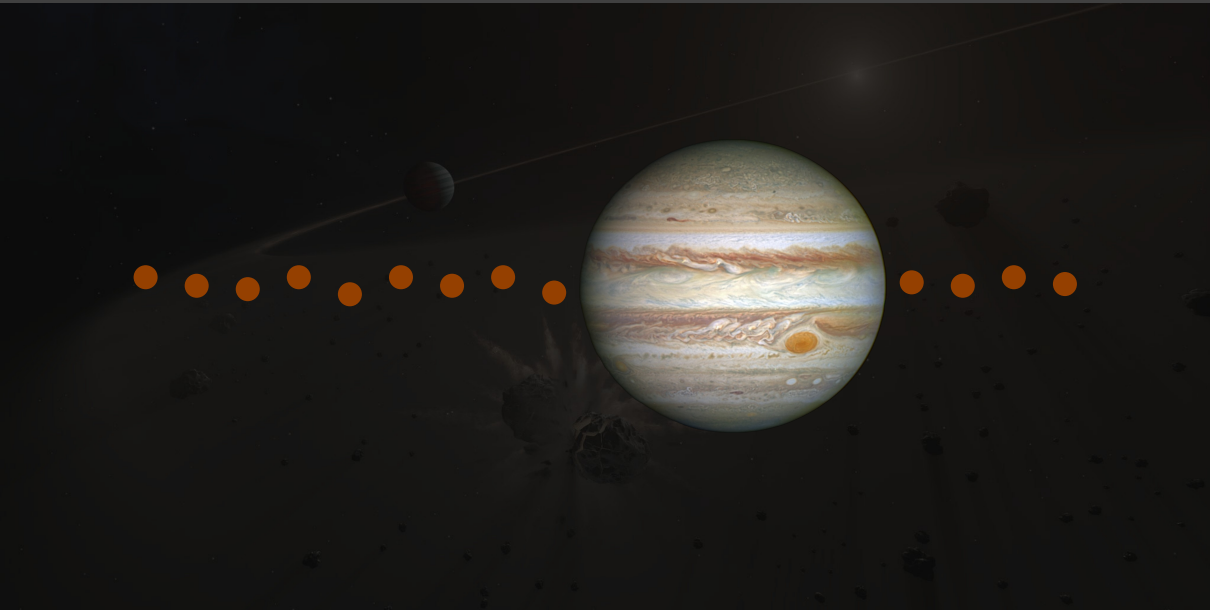


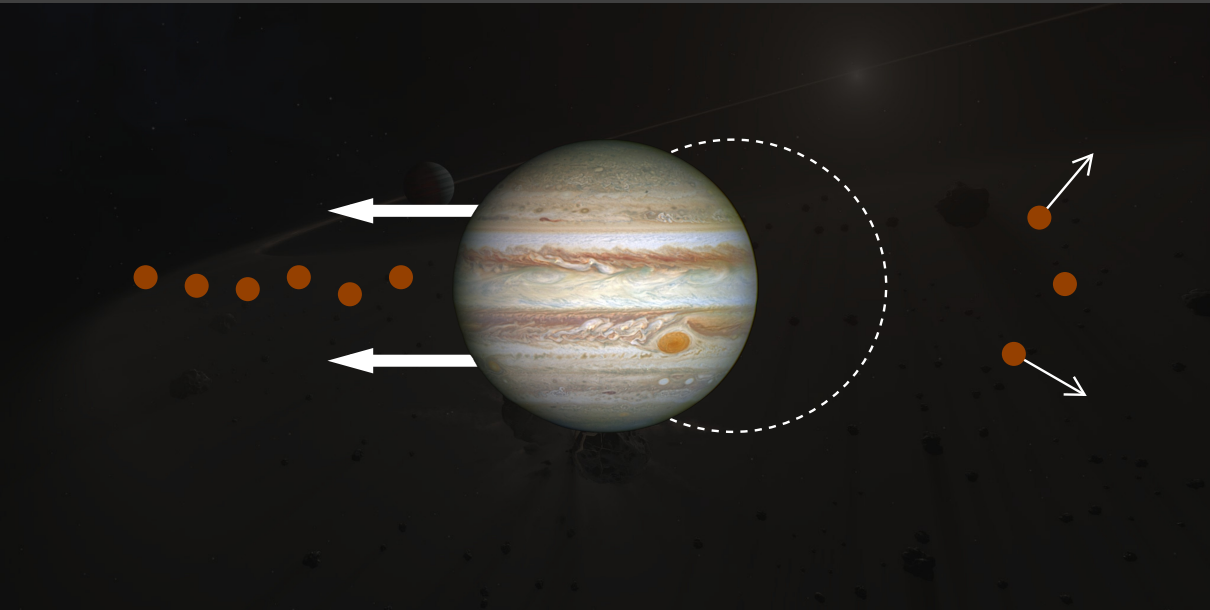
β Pic: Golimowski et al. 2006

4. Planets can stir discs

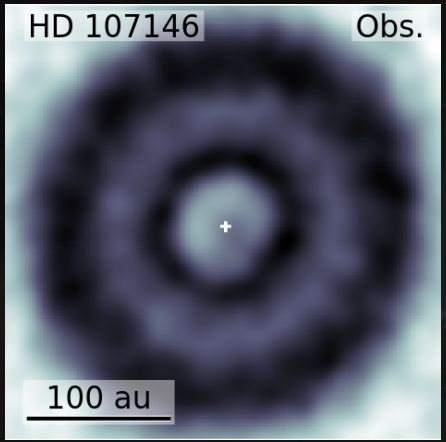
5. Debris can make planets migrate



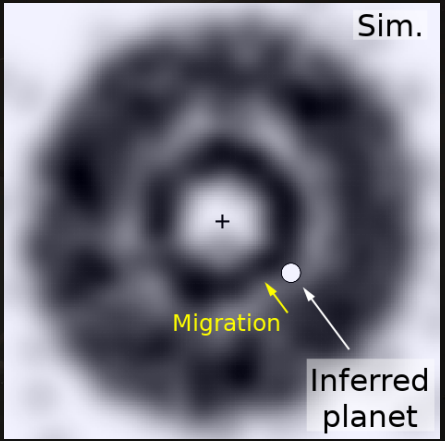
5. Debris can make planets migrate



5. Debris can make planets migrate



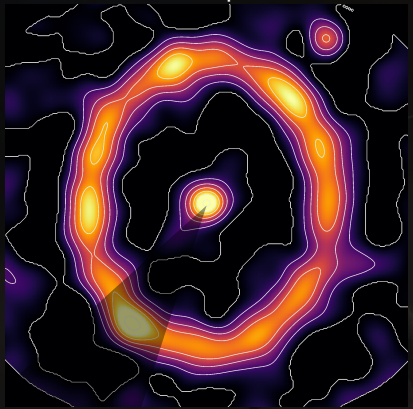
Marino et al. 2018



Friebe, Pearce & Löhne 2022

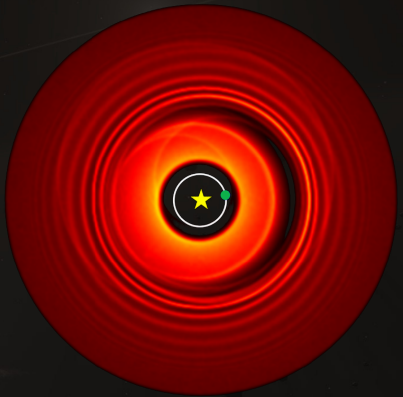
6. Planets can do other stuff too

Clumps



Booth et al. 2023

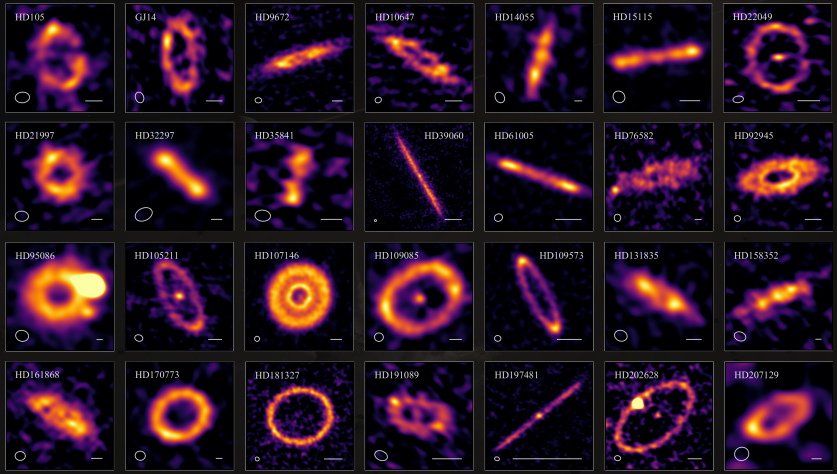
Gaps and spirals



Sefilian, Rafikov & Wyatt 2021

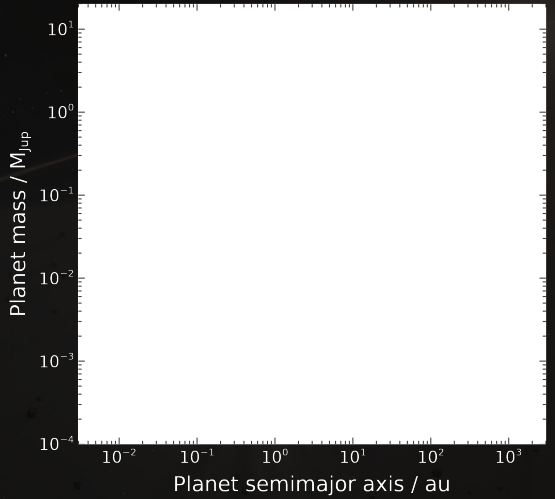
See also: Ida, Larwood & Burkert 2000; Kirsh et al. 2009; Pearce & Wyatt 2015; Yelverton et al. 2019; Friebe, Pearce & Löhne 2022; Sefilian, Rafikov & Wyatt 2023...

Do planets interact with extrasolar debris too?

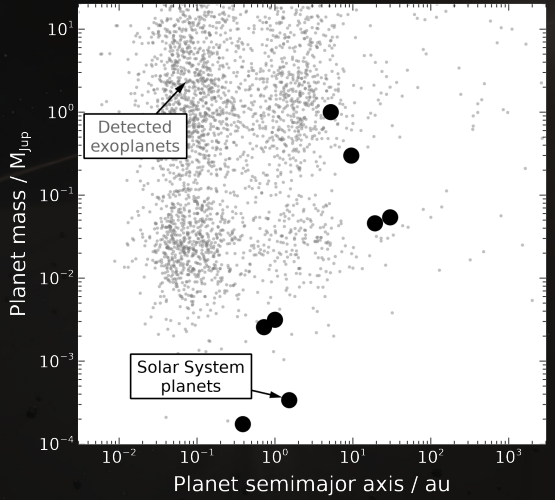


Matrà et al. in prep.

Debris discs as planetary probes

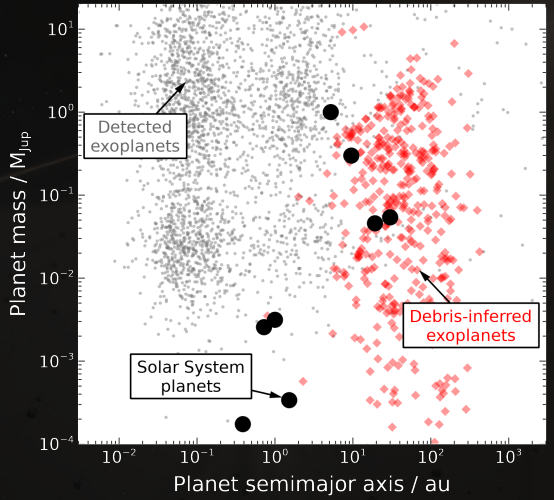


Debris discs as planetary probes



Exoplanet data: Exoplanet.eu

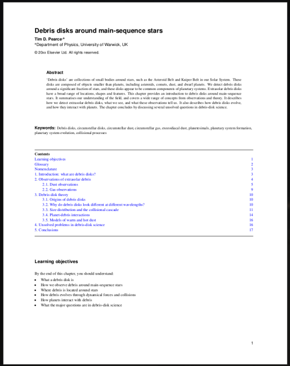
Debris discs as planetary probes



Exoplanet data: Exoplanet.eu

Debris-inferred planets: Pearce et al. 2022

Aside: introduction to debris discs


Debris disks around main-sequence stars

Tim D. Pearce

Department of Physics, University of Warwick, UK

Abstract

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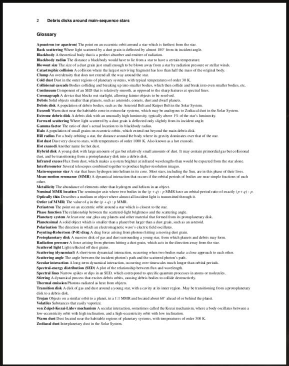
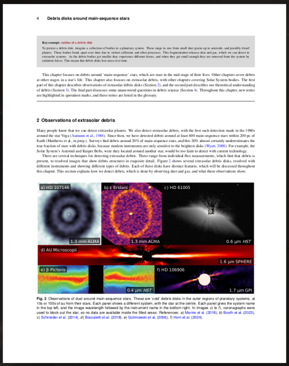
Learning objectives


2 Debris disks around main-sequence stars

Glossary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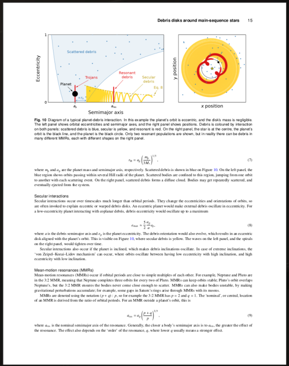
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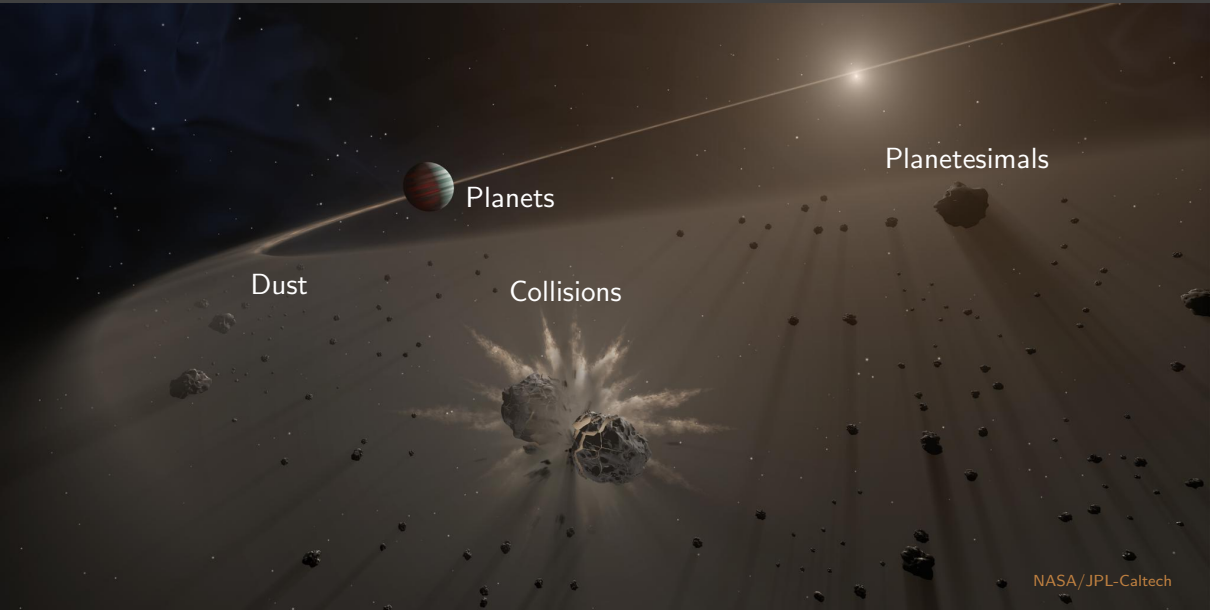
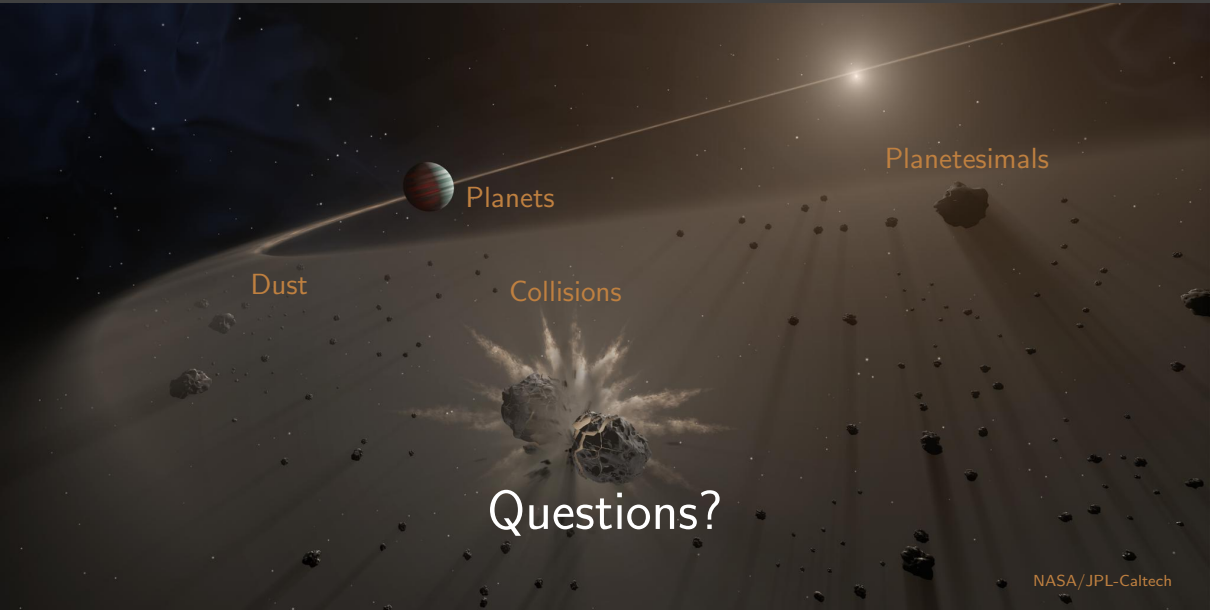
Pearce 2024

Conclusions



Conclusions



Bibliography

Booth M. et al., 2023, MNRAS, 521, 6180

Faramaz V. et al., 2019, AJ, 158, 162

Friebe M. F., Pearce T. D., Löhne T., 2022, MNRAS, 512, 4441

Gáspár A. et al., 2023, Nature Astronomy, 7, 790

Golimowski D. A. et al., 2006, AJ, 131, 3109

Ida S., Larwood J., Burkert A., 2000, ApJ, 528, 351

Jones J. W. et al., 2023, ApJ, 948, 102

Kirsh D. R. et al., 2009, Icarus, 199, 197

MacGregor M. A. et al., 2017, ApJ, 842, 8

Marino S. et al., 2018, MNRAS, 479, 5423

Pearce T. D., 2024, arXiv e-prints, arXiv:2403.11804

Pearce T. D. et al., 2022, A&A, 659, A135

Pearce T. D., Wyatt M. C., 2015, MNRAS, 453, 3329

Sefilian A. A., Rafikov R. R., Wyatt M. C., 2021, ApJ, 910, 13

Sefilian A. A., Rafikov R. R., Wyatt M. C., 2023, ApJ, 954, 100

Yelverton B. et al., 2019, MNRAS, 488, 3588