



From left to right: Boaz Moerman, Joost de Kleuver, Juriaan Metz, Joris Nieuwveld and Casper ten Dam

Observing meter-sized dust collisions in the rings of Saturn to study planetesimal formation

Casper J. ten Dam, Joost H. J. de Kleuver, Boaz C. Moerman, Joris A. Nieuwveld

Supervisor: Dr. Juriaan R. Metz

Abstract: The process of planet formation can be divided into two parts: the formation of km-sized particles, planetesimals, out of microscopic grains and their further growth into planets. Currently it is not understood how from mm- to cm-sized particles planetesimals can be formed. For this it is required to understand more about the physics of dust collisions. Hence extensive experimental research has been done to dust collisions. However, the experimentally testable size range is limited by at most decimeter size. To investigate the collisions between larger particles, we propose to study collisions of m-sized particles in the rings of Saturn. To observe these collisions, NASA's concept mission the Saturn Ring Observer (SRO) would be used. To find out how regularly collisions between Saturn ring particles occur and what the impact of the proposed mission would be on the field of planetesimal formation, we propose to investigate the velocities and frequencies of the collisions between m-sized particles in the rings of Saturn.

Samenvatting: Planeten ontstaan uit microscopisch kleine stofdeeltjes die samen steeds grotere en grotere structuren vormen. Deze groei kan worden verklaard tot op de grootte van centimeters. Tot op heden is het onbekend hoe vanaf daar deeltjes van een paar kilometer groot kunnen vormen. Om deze vraag te beantwoorden moeten we botsingen tussen deze deeltjes beter begrijpen. Dit kan worden onderzocht in laboratoria op Aarde. Deze experimenten zijn met deeltjes van een meter groot in de praktijk echter moeilijk dan wel onmogelijk. Het blijkt daarentegen dat er een natuurlijk laboratorium in ons zonnestelsel bestaat: de ringen van Saturnus. Hier vinden deze botsingen wel plaats. Wij stellen voor om met de Saturn Ring Observer (SRO), een conceptmissie van NASA, deze botsingen te observeren. Hiervoor willen we onderzoeken of de botsingen vaak genoeg voorkomen om ze te kunnen waarnemen en wat de botsingen ons kunnen leren over planeetformatie.

Introduction: One of the most profound question one can ask is: "Where do we come from?" To answer this one must understand the origin of our home planet. This is the reason why the field of planet formation is so fascinating.

Planets are formed in a disk of dust and gas around a young star called a protoplanetary disk. Out of the dust particles increasingly large objects and finally planets are formed. This process can be divided into two parts: firstly, the formation of km-sized objects, planetesimals, out of the microscopic dust particles and secondly, the formation of planets out of planetesimals. The important distinction between the two parts is that gravitational attraction between particles only plays a role in the second part. In the first part, particles can only grow by mutual collisions.

In the formation of planetesimals, there is a big gap in our understanding. The growth from microscopic grains to mm- or cm-sized dust particles can be explained. However, it is poorly understood how these particles can grow to kilometer size.

To understand more about planetesimal formation, one needs to know more about the physics of dust collisions. For this reason, numerous experiments have been done. In these experiments, dust particles of different sizes and materials are shot onto one another in conditions similar to those in a protoplanetary disk. The collisions are filmed in such a way that the resulting particles or fragments can be determined. [1]

The problem with laboratory experiments on Earth is that there is a limit to the sizes of the particles one can work with. Therefore, no experiments have been done with particles larger than a few centimeters. However, it turns out that a natural laboratory exists in our own Solar System: the rings of Saturn. These rings consist of large amounts of water-ice particles with sizes up to a few meters which collide frequently. [1] [2]

A concept mission by NASA, the Saturn Ring Observer (SRO), is to send a satellite to Saturn to study its rings. This spacecraft would hover only 2 to 3 km above the rings, as depicted in **Figure 1**. This is much closer than previous missions have ever been. As a result, it would be able to observe individual collisions between large ring particles. [3]

Mission Concept: We propose to observe collisions between m-sized particles in Saturn's rings using the SRO mission. With enough observations, statistics about the collisions between m-sized particles would be obtained. These statistics could then be used to provide more insight in planetesimal formation.

Research Proposal: A mission concept is not just accepted. It is needed to find out if the collisions of m-sized Saturn ring particles occur regularly enough to observe with SRO and what the collisions would teach us about planetesimal formation. To do this, estimates of the collisional frequencies and collisional velocities of m-sized Saturn ring particles have to be obtained. Firstly, a first estimate has to be made. To do this, research has to be done to the different models of the rings of Saturn. Secondly, the dependence on the position in the rings has to be determined. We would like to know the radial dependence, i.e. the dependence on the distance from Saturn, and the vertical dependence, i.e. the dependence on the distance from the middle of the disk of the ring. Finally, the collisional frequencies and velocities of the m-sized Saturn ring particles have to be obtained for local structures in the rings where these values may be higher. From these calculations, together with the duration of the SRO mission, it can be determined if the collisions of m-sized Saturn ring particles occur regularly enough to observe with SRO.

Furthermore, we would like to determine what observations of SRO would teach us about planetesimal formation. For this reason, a collaborator who is an expert in the field of planetesimal formation is needed. With the collaborator, the properties of the m-sized Saturn ring particles and the particles in protoplanetary disks have to be compared. From this comparison, it can be deduced what the mission could teach us about planetesimal formation.

Outlook: In 2023, NASA will decide whether to continue developing the SRO mission. If the proposed research concludes that SRO would have large relevance for planetesimal formation, the mission could add an extra scientific objective and thus obtain a higher scientific value. If NASA decides to continue with the SRO mission and to include the proposed mission concept to the mission, this research would be important for the realization of the mission. For this reason, the proposed research, which would take 4 years, should be performed now.

References

- [1] J. Blum. Dust evolution in protoplanetary discs and the formation of planetesimals. *Space Science Reviews*, 214(2), 2018. doi: 10.1007/s11214-018-0486-5.
- [2] L. W. Esposito. Composition, structure, dynamics, and evolution of saturn's rings. *Annual Review of Earth and Planetary Sciences*, 38(1):383–410, 2010. doi: 10.1146/annurev-earth-040809-152339.
- [3] P. Nicholson, M. Tiscareno, and L. Spilker. Saturn ring observer study report. 2010. URL <https://solarsystem.nasa.gov/studies/220/saturn-ring-observer-study-report/>.

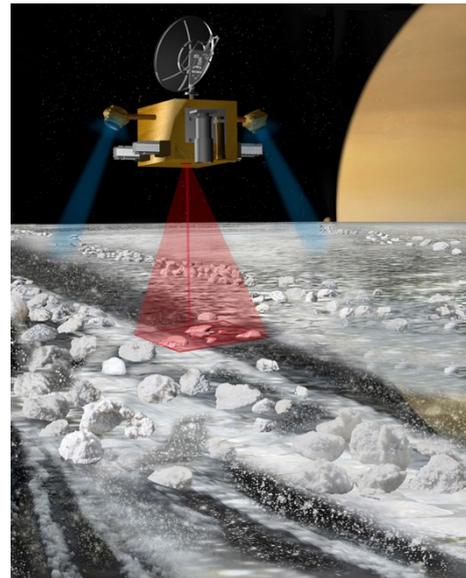


Figure 1: Depicted is a visualization of the spacecraft of the proposed Saturn Ring Observer mission hovering above the rings of Saturn. [3]