## Teams

<table>
<thead>
<tr>
<th>Team</th>
<th>Personnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Team leader and system engineer</td>
<td>Marine</td>
</tr>
<tr>
<td>2. Science</td>
<td>Jonas, Esmee, Julia, Victoria</td>
</tr>
<tr>
<td>2. Payload</td>
<td>John, Adrian, Gwenael</td>
</tr>
<tr>
<td>3. Platform</td>
<td>Marine, Adrian, Fabio, Lisa, Marta</td>
</tr>
<tr>
<td>4. Mission analysis</td>
<td>Mattia, Andre, Jophiel</td>
</tr>
</tbody>
</table>
Contents

1. Science case
2. Payload concept
3. Mission profile
4. Platform
5. Mission design
6. Conclusion
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Science case
Investigating the physics of grain growth

Why study dust growth?

- Planets
- Gaps in knowledge
  - Models
  - 30 µm - 100 µm
  - Low velocity interaction

Why a laboratory in space?

- Remote observations cannot resolve interactions
- Need:
  - Low relative velocities
  - Long time in micro-gravity
  - No big disturbances

Zsom et al. 2010
Science objective

Understand the physics of dust growth at low velocities (<5 mm/s) in protoplanetary disks by observing the evolution of dust size and shape in micro-gravity over long time scales.
The physics of grain growth - Measurements

- Size
  - Same/different initial sizes

- Shape
  - Sample particles

- Composition
  - Quartz/Fayalites separately
  - Porosity

- Rotation frequency

- Ice layers
  - With and without

- Temperature changes
  - Water sublimation
  - T increase

- Relative velocity
  - Before collision

- Type of collision
  - Güttler et al. 2010
The physics of grain growth - Environment

- Gas: dust mass ratio = 100 : 1 for µm-sized particles
- Magnetic field: expected to be in the order of ~2.9\times10^{-5} T inside the volume
- Temperature: < 230 K inside the volume
- Pressure: between 0.1 - 6 mbar inside the volume
Initial experimental conditions

- **Monodisperse**
  - Varying composition:
    - 4 different initial grain sizes
    - 4 different compositions each
  - Varying porosity:
    - 1 initial grain size
    - 4 different porosity distributions
- **Polydisperse**
  - Varying size distribution:
    - 2 different initial size distributions
    - 4 different compositions each

→ 28 experiments in total
Payload
## Measurement requirements

<table>
<thead>
<tr>
<th>Scientific requirement</th>
<th>Measurement requirement</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure of size</td>
<td>The size shall be measured in the range between 1 µm and 1cm with a precision of 10%.</td>
<td>Analyze how the size of the incoming particles affect the grain growth.</td>
</tr>
<tr>
<td>Measure of relative velocity</td>
<td>The relative velocity of incoming and outgoing particles shall be measured in the range between 1µm/s and 5 mm/s with a precision of 1%.</td>
<td>Analyze the influence of relative velocity in the grain growth.</td>
</tr>
<tr>
<td>Measure of rotational velocity</td>
<td>The rotational velocity of incoming particles shall be measured at 120 fps (frames per second).</td>
<td>Analyze possible influence of rotation in the particle interaction and grain growth.</td>
</tr>
</tbody>
</table>
## Measurement requirements: timescale

<table>
<thead>
<tr>
<th>Measurement requirements</th>
<th>Driving science requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least $10^6$ collisions shall be recorded during each experiment.</td>
<td>S1, S2, S3, S4, S5, S7</td>
</tr>
<tr>
<td>The mean free path of grains shall not exceed 0.01 of the smallest dimension of the containing volume.</td>
<td>S1, S2, S3, S4, S5, S7</td>
</tr>
<tr>
<td>The experimental volume shall be sampled at least once every 2 hours.</td>
<td>S1, S3, S7</td>
</tr>
</tbody>
</table>
## Measurement requirements: cleanliness

<table>
<thead>
<tr>
<th>Measurement requirements</th>
<th>Driving science requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>No more than 20% of particles may be stuck to the walls of the containing volume during any experiment</td>
<td>S1, S2, S3, S4, S5, S7</td>
</tr>
<tr>
<td>The speed of particles released from walls after any agitation shall not exceed 2 mm s(^{-1})</td>
<td>S1, S2, S3, S4, S5, S7</td>
</tr>
<tr>
<td>No more than 1% of particles may remain in the chamber after each experiment</td>
<td>S1, S2, S3, S4, S5, S7</td>
</tr>
</tbody>
</table>
## Main instruments

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Qty</th>
<th>Measurement requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size Range</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Collision type</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Shape</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Velocity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rate of rotation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Porosity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particle tracking camera (P-CAM)</td>
<td>3</td>
<td>Yes</td>
</tr>
<tr>
<td>Size Range</td>
<td>1 cm - 3 µm</td>
<td>Yes</td>
</tr>
<tr>
<td>Collision type</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Shape</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Velocity</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Rate of rotation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Porosity</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Optical Microscope (OM)</td>
<td>1</td>
<td></td>
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<tr>
<td>Size Range</td>
<td>50 - 1 µm</td>
<td>Yes</td>
</tr>
<tr>
<td>Collision type</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Shape</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Rate of rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porosity</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Atomic Force Microscope (AFM)</td>
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</tr>
<tr>
<td>Size Range</td>
<td>1 - 0.1 µm</td>
<td>Yes</td>
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<tr>
<td>Collision type</td>
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<tr>
<td>Shape</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Rate of rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porosity</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
Measurement principles

Particle tracking

Optical microscopy

Atomic force microscopy
Instrument description

Particle Tracking Camera (P-CAM)

Heritage: Phoenix (MARDI)
Mass: 1.5 kg
Power: 4 W
Data rate: 5.4 Mb s\(^{-1}\)
Volume: 70x70x70 mm

Optical Microscope (OM)

Heritage: Rosetta (CIVA-M/V)
Mass: 1.1 kg
Power: 1 W
Data rate: 0.075 Mb s\(^{-1}\)
Volume: 70x50x91 mm

Atomic Force Microscope (AFM)

Heritage: Rosetta (MIDAS)
Mass: 8.3 kg
Power: 17 W
Data rate: 0.001 Mb s\(^{-1}\)
Volume: 300x250x100 mm
Payload design

- Close range instruments: - AFM - OM
- GELATO
- Step engine
- Frame
- Experimental volume
- Cameras
- Agitator
- Carousel

24
Identify sample tube containing desired dust
Rotate carousel to align sample tube with injection port
Start engineering camera to observe dust injection
If ice layer required on dust, open valve at chamber
If ice layer required on dust, inject H2O
If ice layer required on dust, wait
Open valves for dust injection
Modulate high-pressure gas flow to inject and disperse dust
Close valves and wait for dust to disperse
Start particle tracking cameras
Start experiment clock. Record collisions using particle tracking cameras
Agitate chamber using off-axis motor and low-amplitude resonator to release dust stuck to walls
Agitations carried out periodically throughout experiment
Pre-programmed sampling time reached. Identify position of grain grabber in carousel.
Rotate carousel to align grain grabber with injection port
Extend grain grabber on linear telescopic actuator to sample grains
Retract grain grabber head back into carousel with dust grains attached
Rotate grain grabber to align head with optical microscope
Inspect grains at close range using optical microscope (OM)
Rotate grain grabber to align head with Atomic Force Microscope (AFM)
Rotate grain grabber to align head with Atomic Force Microscope (AFM)
Inspect grains at close range using Atomic Force Microscope (AFM)
Rotate grain grabber to align head with Grain Grabber Cleaner (GG-CLEAN)
Rotate grain grabber to align head with Grain Grabber Cleaner (GG-CLEAN)
Clean grain grabber head and expel particles to vacuum
Repeat sampling periodically throughout experiment. GG cleanliness can be inspected using OM.
When target number of collisions reached, or experiment timeout, stop particle tracking cameras
Rotate carousel to align vent tube with injection port
Rotate carousel to align vent tube with injection port
Open vent valves
Let gas into chamber to achieve desired overpressure for dust ejection
Agitate volume to release any dust stuck to walls
Modulate gas flow to vent dust to vacuum. Repeat as required.
Close valves

<table>
<thead>
<tr>
<th>PRE-EXPERIMENT ACTIVITY</th>
<th>EXPERIMENT</th>
<th>POST-EXPERIMENT ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGITATION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAMPLING</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ready for next experiment

<table>
<thead>
<tr>
<th>Pre-experiment Activity</th>
<th>Experiment</th>
<th>Post-experiment Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agitation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sampling</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

60
The video cameras are working constantly to record the collisions between particles. The volume of data is really huge, 41.616 Gb/s, which is problematic to send to Earth, so we need to process it onboard.

Using particle tracking, a program can detect the movement of a particle. It is possible then to calculate the linear velocity of incident particles and collisional products. This satisfies then the requirement of S4.

Using particle tracking, a program can detect the movement of positions of a particle. It is possible then to calculate the size, the inclination of the rotational axis, and the three rotational velocities around the three angular axes for the incident particles. This satisfies then the requirement of S1 and S5.

For particles with an effective radius of 10 micrometer or bigger, we want to see the shape of the incident particles and the shape and collision type of the collisional products. For this, we will send a picture of the particles. This satisfies the requirement of S1, S2 and S3.

Resulting data is expected to be under 17 Mb/s.

### On-board data processing

<table>
<thead>
<tr>
<th>Data type</th>
<th>Maximum data generation rate (Mb s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw</strong></td>
<td></td>
</tr>
<tr>
<td>Total raw data</td>
<td>42000</td>
</tr>
<tr>
<td>After processing</td>
<td></td>
</tr>
<tr>
<td>Particle velocities</td>
<td>8</td>
</tr>
<tr>
<td>Particle rotation rates</td>
<td>9</td>
</tr>
<tr>
<td>Particle images</td>
<td>0.3</td>
</tr>
<tr>
<td>Total after processing</td>
<td>17</td>
</tr>
</tbody>
</table>

![Diagram of particle velocities and rotation rates](image)
Key technology development plan - Grain Grabber

- Current TRL: 2
- Function
  - Collect sample
  - Hold samples
- Requirement
  - Reusability
  - Long stroke
- Solution
  - Linear actuator
  - Static charger
  - Piezo actuator (Curiosity heritage)
- Verification
  - Lab testing
  - Micro-g for grain adhesion
Key technology development plan - GELATO

- Current TRL: 2
- Function
  - Apply ice layer to dust particles
- Requirement
  - Diffuse gaseous \( \text{H}_2\text{O} \)
- Solution
  - Based on fuel injectors
  - Aerosol experiments
- Verification
  - Lab testing
  - Micro-g for grain adhesion
Key technology development plan - Carousel

- **Current TRL:** 2
- **Function**
  - Hold sample container
  - Rotate Grain Grabber
- **Requirement**
  - Hold multiple experiments
  - 1m radius
- **Solution**
  - Curiosity SAM module Heritage
  - Counter mechanism
- **Testing:**
  - Earth laboratory
  - Micro-G
Mission profile
Objectives, requirements, and drivers

Mission objectives

Achieve all planned science experiments
Downlink and analyse data on the ground

Main system drivers and mission requirements

- Long duration in microgravity
- Minimal external disturbances
- Thermal control
- Data rate
**Pre-flight**
- Prepare grain canisters

**Transit**
- Env. conditions on launch

**Launch**
- Soyuz
- Sun-Synchronous
- 800 km
- Mass < 2t
- Shared ride possible.

**Commissioning**
- Eliminate rotation
- System check
- Initiate science

**Experiment**
- Release sample
- Take measurements
- Vent chamber

**Housekeeping**
- Reorbit
- Diagnosis

**Detumble**
- Stabilize
- Obtain attitude
- Deploy comms
- Deploy solar

**Pre-flight**
- Prepare grain canisters
### Launcher and transfer

Launch Vehicle: Soyuz  
Target: SSO 800 km  
Launch Base: Guiana Space Center

<table>
<thead>
<tr>
<th>Orbit</th>
<th>Altitude</th>
<th>Inclination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection</td>
<td>785 ± 12 km</td>
<td>98.6° ± 0.12°</td>
</tr>
<tr>
<td>Target</td>
<td>800 km</td>
<td>98.6°</td>
</tr>
</tbody>
</table>
**Orbit**

Launch site: Guyana Space Center  
Orbit type: Sun-synchronous  
Altitude: 800 km  
Inclination: 98.6°  
RAAN: 6:00 pm  
RADN: 6:00am

- Long access times for the downlink  
- Thermal stability  
- No attitude corrections to point at the sun  
- Acc. from drag & Solar pressure $\sim 10^{-7}$ m/s$^2$
# Delta V Budget

<table>
<thead>
<tr>
<th></th>
<th>Delta V [m/s]</th>
<th>Fuel mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Injection</strong></td>
<td>37.85</td>
<td>15.3</td>
</tr>
<tr>
<td><strong>Station Keeping</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 Year</td>
<td>1 Year</td>
</tr>
<tr>
<td></td>
<td>Mission 10 Years</td>
<td>Mission 10 Years</td>
</tr>
<tr>
<td>Inclination</td>
<td>5.1</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>17</td>
</tr>
<tr>
<td>Drag</td>
<td>2.4</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td><strong>Collision avoidance</strong></td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Deorbit</strong></td>
<td>74.8</td>
<td>31.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>188</td>
<td>71.7</td>
</tr>
</tbody>
</table>
Deorbiting

Deorbiting time: 24.5 Years
Further analysis for safe disposal has to be made
Operations and ground segment

- Redu GS - TT&C subsystem - 2.4 m antenna operating in S-Band
  - 100 kbps up, 2 Mbps down
- Kiruna GS - Scientific data downlink - 15 m antenna operating in X-Band
  - 191.4 GB downloaded per day at 175 Mbps
  - 12 passes per day to download scientific data
  - Each pass consists of 730 seconds (~12 minutes)
Overview of subsystems

Structure

Payload

- OBC
- OBDH

- TM/TC S-Band
- Science X-Band

Telecom

- Coating
- SunShield
- MLI
- Louvers

Thermal Control

- Batteries
- PDCU
- Solar Panels

Power

- Deorbit Thrusters
- Propellant Tank

Propulsion

- Sun Sensor
- Magnetotorquer
- Star Traker
- Momentum Wheel
- Drag Free Acc.
- Electric Thruster
- IMU
- GNSS

AOCS
System drivers

Structure

Payload

OBC
OBDH

Batteries
PDCU

Solar Panels
Power

Deorbit Thrusters

Propellant Tank
Propulsion

Coating
SunShield
MLI
Louvers
Thermal Control

TM/TC
S-Band
Telecom

Science
X-Band

Sun Sensor
Magnetotorquer
Star Traker
Momentum Wheel
Drag Free Acc.
Electric Thruster
IMU
GNSS
AOCS
Spacecraft configuration

1. Solar panels
2. Sun shield
3. Spacecraft bus
4. Payload container
5. Louvres for thermal control
6. Quartz mirror for thermal control
7. Frame
8. Ion thrusters for attitude control (x6)
9. Hydrazine thrusters (x4)

Spacecraft dimensions:

H: 4400 mm
W: 2800 mm
L: 2800 mm

Sunshield: Ø 5000 mm
Spacecraft configuration

Spacecraft in stowed arrangement compared with the Soyuz fairing usable volume and a human for scale.

Magrathea - concept model
Propulsion subsystem

- **Functions**
  - Orbit injection and correction maneuver
  - Detumbling phase
  - Station keeping
  - Debris avoidance
  - End of life maneuver

- **Driver**
  - Safe deorbiting at EOL

- **Solution**
  - 4 x 20 N monopropellant hydrazine
  - Isp = 220 s
  - DeltaV = 164 m/s

- **Technology readiness**
  - TRL 9
AOCS subsystem

- **Functions**
  - Minimize disturbances to experiment
  - Drag-counter control attitude

- **Driver**
  - Counter all external forces
  - Pointing capability for communications

- **Technology readiness**
  - TRL9
Thermal subsystem

- **Functions**
  - Provide required temperatures for experiment and bus
  - Account for IR emission from Earth

- **Solution**
  - MLI
  - Sun shield
  - Coating
  - Louvres
  - Heaters
  - Optical surface reflector

- **Maturity**
  - TRL9 but high criticality

<table>
<thead>
<tr>
<th>Thermal Model</th>
<th>Bus</th>
<th>Experiment Chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
<td>Cold</td>
<td>Hot</td>
</tr>
<tr>
<td>Equilibrium temp. with louvers/ heaters [K]</td>
<td>263 (-10°C)</td>
<td>293 (20°C)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Power subsystem

- **Functions**
  - Sustain all the equipment of the spacecraft (payload and SM) with required power

- **Solution (900W)**
  - **Battery Cells**
    - N°cells = 10
    - Energy = 100 Wh
    - Mass = 1.25 kg
  - **Solar Arrays**
    - Power max = 900 W
    - Area = 6.3 m^2
    - Mass = 16.4 kg
  - **Power Distribution & Control Unit**
    - Power max = 900 W
    - Efficiency = 97 %
    - Mass = 0.6 kg

- **Technology readiness**
  - TRL9

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td>373</td>
</tr>
<tr>
<td>Platform</td>
<td>489</td>
</tr>
<tr>
<td><strong>Total (margin 20%)</strong></td>
<td><strong>863</strong></td>
</tr>
</tbody>
</table>
C&DH subsystem

PAYLOAD OBDH : Sirius C&DH

Performance

Processor software = 32-bit OpenRISC fault-tolerant processor
Mass memory storage = 124 GB

Payload

Storage capacity = 4 GBytes
Storage capacity flash = 16 GBytes non-volatile
Power consumption = 15W

Functions

- On board science data reduction and particle tracking
- Data storage
- Housekeeping data handling

Technology readiness

- TRL9
Communications

● Requirement
  ○ Download all the scientific and housekeeping data

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>Data rate</td>
<td>175</td>
<td>Mb/s</td>
</tr>
<tr>
<td>Daily data volume</td>
<td>191.4</td>
<td>GB</td>
</tr>
<tr>
<td>Data downlink/pass</td>
<td>16</td>
<td>GB</td>
</tr>
<tr>
<td>Data downlink/day</td>
<td>191.6</td>
<td>GB</td>
</tr>
</tbody>
</table>

● Solution
  ○ Two S-Band patch antennas and transceivers for TT&C (housekeeping)
  ○ X-Band horn antenna and transmitter for data downlink
  ○ Use of different ground stations for each purpose

● Technology readiness: TRL9
## Main budgets

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Margin</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td>35%</td>
<td>289</td>
<td>454</td>
</tr>
<tr>
<td>Telecom</td>
<td>20%</td>
<td>23</td>
<td>66</td>
</tr>
<tr>
<td>OBDH</td>
<td>20%</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>Power</td>
<td>20%</td>
<td>29</td>
<td>27</td>
</tr>
<tr>
<td>AOCS</td>
<td>20%</td>
<td>84</td>
<td>266</td>
</tr>
<tr>
<td>Propulsion</td>
<td>20%</td>
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<tr>
<td>Thermal</td>
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<tr>
<td>Structure</td>
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<tr>
<td>Propellant</td>
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<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>Wet: 1033</strong></td>
<td><strong>891</strong></td>
</tr>
</tbody>
</table>
Mission design
Cost Analysis

### Spacecraft Elements

<table>
<thead>
<tr>
<th>Element</th>
<th>MEUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instruments</td>
<td>88</td>
</tr>
<tr>
<td>S/C Bus</td>
<td>135</td>
</tr>
</tbody>
</table>

### Mission and Programmatic elements

<table>
<thead>
<tr>
<th>Element</th>
<th>MEUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Spacecraft cost</td>
<td>223</td>
</tr>
<tr>
<td>ESA Programme Level</td>
<td>27</td>
</tr>
<tr>
<td>Integration, Assembly &amp; Test (IA&amp;T)</td>
<td>22</td>
</tr>
<tr>
<td>Ground Operations (MOC, SOC)</td>
<td>31</td>
</tr>
<tr>
<td>Flight software</td>
<td>20</td>
</tr>
<tr>
<td>Launch vehicle (Soyuz)</td>
<td>75</td>
</tr>
<tr>
<td><strong>Margin</strong></td>
<td>10%</td>
</tr>
<tr>
<td><strong>Total with margin</strong></td>
<td>438</td>
</tr>
</tbody>
</table>
Risk Analysis

R1: Chamber agitation
R2: Chamber contamination
R3: Louvre blocking (thermal)
R4: Thermal chamber instability
R5: Solar radiation
R6: Debris impact
R7: Chamber venting
R8: Water condensation
R9: Technology development (Sample handling and processing SS - TRL2)
R10: Wall sticking
Development schedule

- **PHASE 0: MISSION ANALYSIS**
  - MDR: Mission Definition Review
  - 1 year

- **PHASE A: FEASIBILITY STUDY**
  - PRR: Preliminary Requirements Review
  - 2 years

- **PHASE B: PRELIMINARY DEFINITION**
  - SRR: System Requirements Review
  - PDR: Preliminary Design Review
  - 1 year

- **PHASE C: DETAILED DEFINITION**
  - CDR: Critical Design Review
  - 7 years

- **PHASE D: PRODUCTION AND QUALIFICATION**
  - FRR: Flight Readiness Reviews
  - 1 year

Total: 11 years

> Expected launch date: 2030
Descoping options

- Reduce number of experiments according to science priority
- Remove ice-layer generation capability (GELATO)
- Remove Atomic Force Microscope
Outreach - Middle school
Outreach - College
Outreach - College

drop your thesis!

fly your thesis!
Thank you for the Alpbach summer school!
Appendix slides
Long experiments provide insight on grain growth.

Long experiments provide meaningful statistics on:

- Collision type
- Requirement for sticking
- Physics of collisions
### Measurement requirements (old version)

<table>
<thead>
<tr>
<th>Science requirements</th>
<th>Measurement requirements (M1 - M8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand how the following parameters affect dust grain growth in protoplanetary</td>
<td>Min.</td>
</tr>
<tr>
<td>disks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S1: size ($r_{\text{eff}}$) 0.5 µm 1 cm ± 0.1 µm</td>
</tr>
<tr>
<td></td>
<td>S2: collision type Classify collision type according to Guttler et al. 2010</td>
</tr>
<tr>
<td></td>
<td>S3: shape ± 0.1 µm</td>
</tr>
<tr>
<td></td>
<td>S4: rel. velocity 1 µm s$^{-1}$ 5 mm s$^{-1}$ ± 10 %</td>
</tr>
<tr>
<td></td>
<td>S5: rotation rate 0 rev s$^{-1}$ 60 rev s$^{-1}$ ± 1 %</td>
</tr>
<tr>
<td></td>
<td>S6: composition N/A - compositions selected before launch</td>
</tr>
<tr>
<td></td>
<td>S7: porosity ($\varphi$) 0 1 ± 1 %</td>
</tr>
<tr>
<td></td>
<td>S8: ice mantle N/A - icy mantle produced during grain injection</td>
</tr>
</tbody>
</table>
## Particle tracking camera

<table>
<thead>
<tr>
<th>Measurement requirement</th>
<th>Specification</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need to resolve 1 cm$^2$ in spaces of 3 µm</td>
<td>Size of pixel</td>
<td>Side of 5.5 µm, total surface of 30.25 µm$^2$</td>
</tr>
<tr>
<td>Need to measure 1 cm$^3$</td>
<td>Number of pixels</td>
<td>11.56 MP (3400x3400)</td>
</tr>
<tr>
<td>Need to resolve rotations</td>
<td>Frames per second</td>
<td>120 fps</td>
</tr>
<tr>
<td>Need to see the volume</td>
<td>Field of view</td>
<td>8.265°</td>
</tr>
</tbody>
</table>
Antennas

- **TT&C**: two S-Band patch antennas and transceivers
  - Gain: 8 dB
  - Half Power Beam Width (HPBW): 71°
  - Transmitted power: 20 dBm

- **Data downlink**: X-Band horn antenna and transmitter
  - Gain: 10 dB
  - Half Power Beam Width (HPBW): 55°
  - Transmitted power: 37.8 dBm
# Link budget

<table>
<thead>
<tr>
<th></th>
<th>S up (100 kbps)</th>
<th>S down (2 Mbps)</th>
<th>X down (175 Mbps)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EIRP</strong></td>
<td>32.23</td>
<td>-2</td>
<td>17.78</td>
<td>dBW</td>
</tr>
<tr>
<td><strong>Path losses</strong></td>
<td>156.96</td>
<td>157.36</td>
<td>169.1</td>
<td>dB</td>
</tr>
<tr>
<td><strong>G/T</strong></td>
<td>-22</td>
<td>9.62</td>
<td>37.29</td>
<td>dB/K</td>
</tr>
<tr>
<td><strong>EB/NO</strong></td>
<td>29.87</td>
<td>13.85</td>
<td>30.14</td>
<td>dB</td>
</tr>
<tr>
<td><strong>Required EB/NO</strong></td>
<td>8</td>
<td>8</td>
<td>14</td>
<td>dB</td>
</tr>
<tr>
<td><strong>Margin</strong></td>
<td>21.87</td>
<td>5.85</td>
<td>16.14</td>
<td>dB</td>
</tr>
</tbody>
</table>
Thank you tutors!
Thank you tutors!
Thank you tutors!