OVER THE DUSTY MOON CHALLENGE

SPACESHIP TEAM

SPACESHIP EAC

Over the Dusty Moon - How to Transport Lunar Soil

We are going back to the Moon!

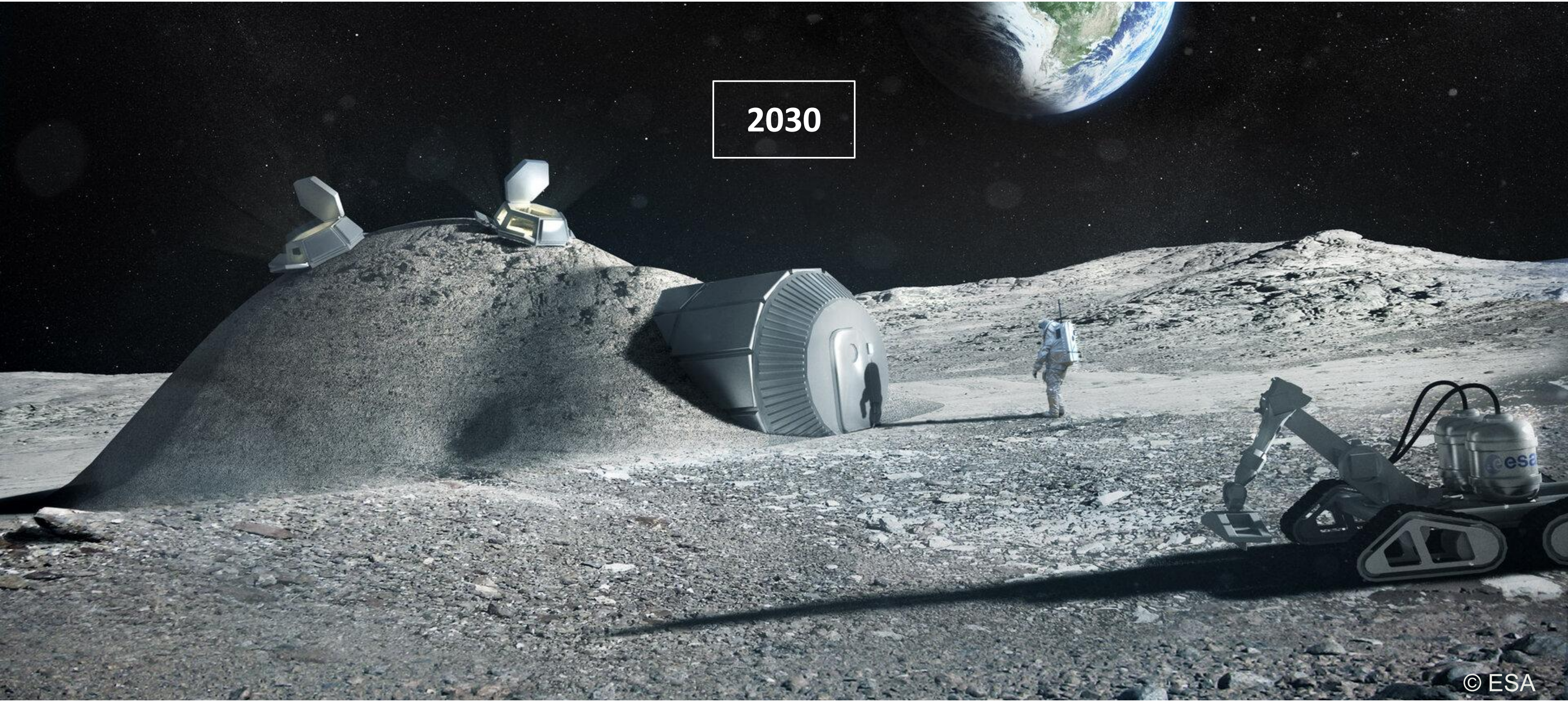
2022

2024

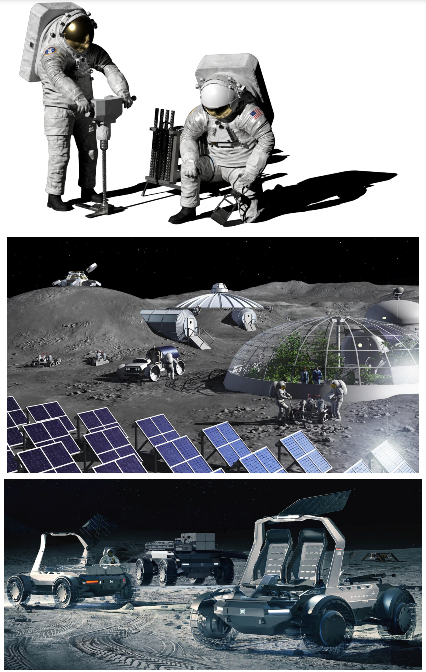
GATEWAY

ARTEMIS

We are going back to the Moon!



But… Why?

Science	Technology	Test-bed for Mars	Resources
			
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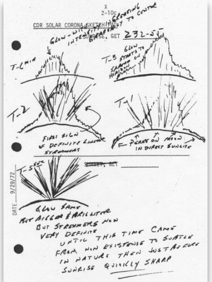
Lunar environment (Heiken, et al. 1991)

Vacuum

- Exosphere (3x10^{-15} atm)
- No protection against micrometeoroids
- Outgassing!
- No convective heat transfer - thermal control



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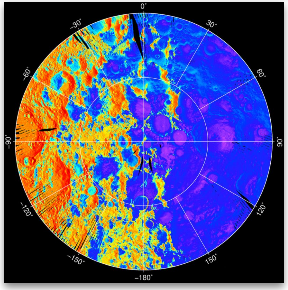
Temperature

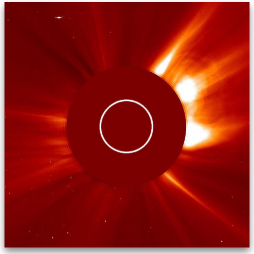
- Between 107 and -233 ºC
- Extreme temperature gradients: thermal fatigue and distortions
- Thermal shocks constrains material selection



J.P. Williams et al. (2019)

Radiation

- Electromagnetic and particle radiation
- No atmosphere, no protection
- Degradation of solar cells and electronics



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Gravity

- Gravitational pull is 1/6th of Earth's
- Vehicles will have less tractive force
- Light gases escape the gravitational pull

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Lunar environment (Heiken, et al. 1991)

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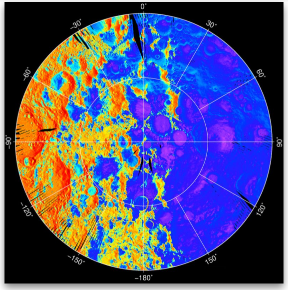

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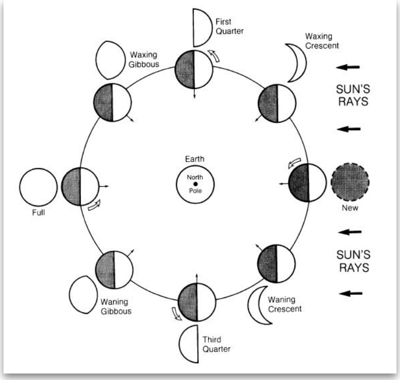
J.P. Williams et al. (2019)

Lunar night

- Lunar rotation is gravitationally locked to Earth - nights last for 14 terrestrial days
- Other energy source than solar or big scale storage is required
- Thermal control of habitats becomes crucial at nighttime



Heike, et al. (1991)

R

- Electromagnetic and
radiation
- No atmosphere, no p
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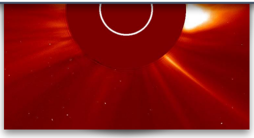

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h of Earth's

- Vehicles will have less tractive force
- Light gases escape the gravitational pull

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The lunar regolith (Heiken, et al. 1991)

© Nature

"The surface is fine and powdery. I can pick it up loosely with my toes. It does adhere in fine layers like powdered charcoal to the sole and sides of my boots [...] I can see the footprints of my boots and the treads in the sandy particles"

Neil Armstrong, as he stepped onto the Moon

The lunar regolith (Heiken, et al. 1991)

© Nature

Lunar regolith is the layer of fragmented rocks that covers the moon. It can have sizes of the order of microns and is highly abrasive.

The lunar regolith (Heiken, et al. 1991)

Table 1: Main constituents of the average lunar soil according to Apollo 15 measurements [7] and principal chemical elements according to Apollo 15 and 16 data [8].

Compound	Average Soil	Element	Average Soil
SiO_2	46.61	O	60.9
TiO_2	1.36	Na	0.4
Al_2O_3	17.18	Mg	4.2
FeO	11.62	Al	9.4
MgO	10.46	Si	16.4
CaO	11.64	Ca	5.8
Na_2O	0.46	Ti	0.3
K_2O	0.20	Fe	2.3
P_2O_5	0.19		
MnO	0.16		
Cr_2O_3	0.25		

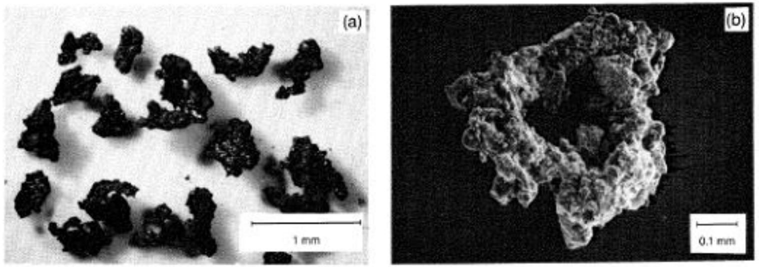

Fig. 7.2. Typical lunar soil agglutinates. **(a)** Optical microscope photograph of a number of agglutinates separated from Apollo 11 soil sample 10084, showing a variety of irregular agglutinate shapes (NASA Photo S69-54827). **(b)** Scanning electron photomicrograph of a doughnut-shaped agglutinate. This agglutinate, removed from soil 10084, has a glassy surface that is extensively coated with small soil fragments. A few larger vesicles are also visible (NASA Photo S87-38812).

Lunar regolith is the layer of fragmented rocks that covers the moon. It can have sizes of the order of microns and is highly abrasive.

It is composed of mineral fragments, glasses and agglutinates. These minerals contain are mostly silicates and oxides that contain a significant amount of **oxygen and metals.**

The lunar regolith (Heiken, et al. 1991)

© NASA Archives

Lunar regolith is the layer of fragmented rocks that covers the moon. It can have sizes of the order of microns and is highly abrasive.

It is composed of mineral fragments, glasses and agglutinates. These minerals contain are mostly silicates and oxides that contain a significant amount of **oxygen and metals.**

Due to the vacuum and solar wind it is **electrostatically charged**, which makes it sticky and can remain suspended for long times.

The dangers of the dust

“After lunar liftoff . . . a great quantity of dust floated free within the cabin. This dust made breathing without the helmet difficult, and enough particles were present in the cabin atmosphere to affect our vision. The use of a whisk broom prior to ingress would probably not be satisfactory in solving the dust problem, because the dust tends to rub deeper into the garment rather than to brush off”

Alan Bean, 1970

Apollo 17 astronaut, Eugene Cernan © NASA Archives

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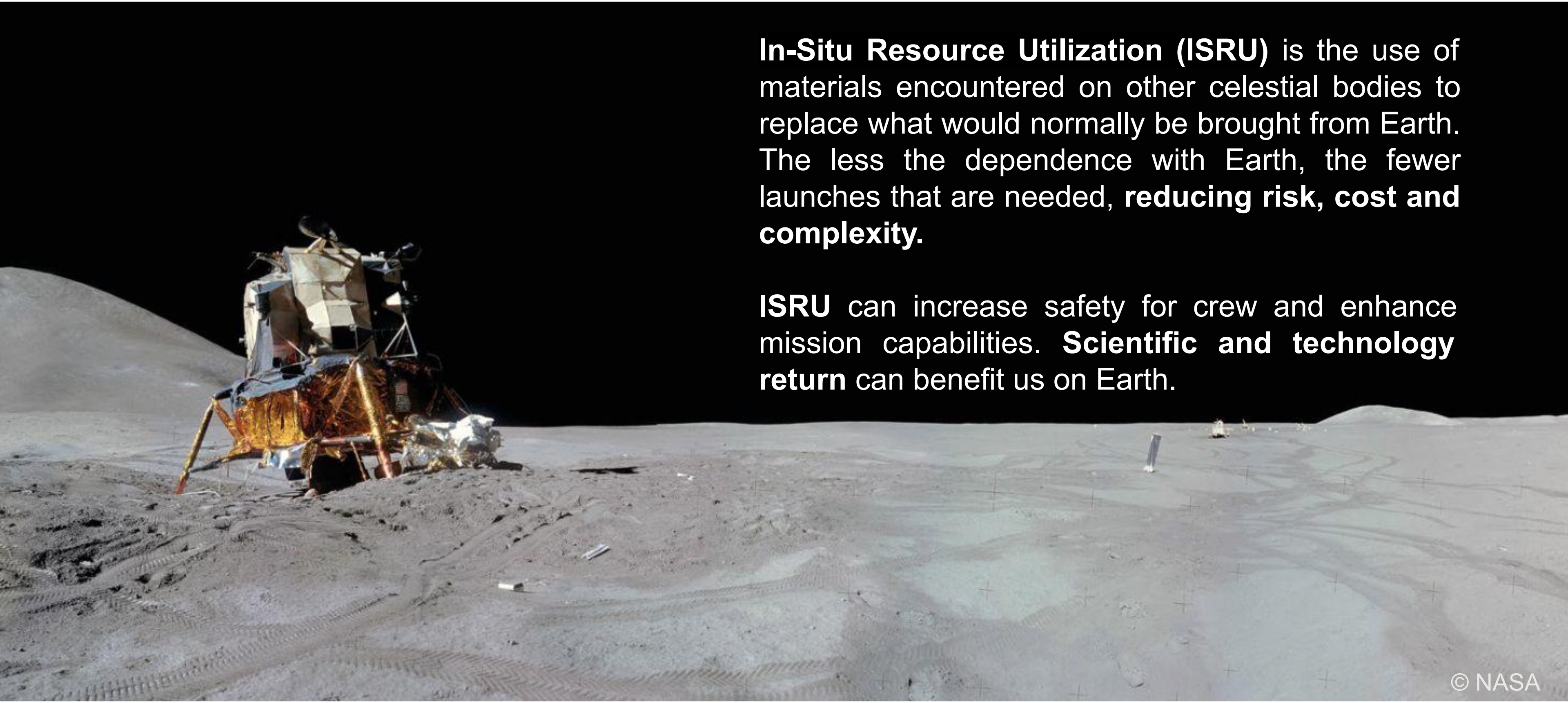
The dangers of the dust (Heiken, et al. 1991)

Lunar dust is the regolith particles smaller than 20 microns. The lack of erosion processes makes dust particles angular and sharp; hence, its **abrasive behavior**.

As the dust sticks to most surfaces it adheres to spacesuits, tools, equipment and solar cells among others, **greatly damaging mechanical parts** (as bearings or gears).

Dust also has a great impact on the crew's health: all astronaut that stepped on the experienced **"lunar hay fever"**, difficulting nominal operations on the moon.

In-Situ Resource Utilization (ISRU)



In-Situ Resource Utilization (ISRU) is the use of materials encountered on other celestial bodies to replace what would normally be brought from Earth. The less the dependence with Earth, the fewer launches that are needed, **reducing risk, cost and complexity.**

ISRU can increase safety for crew and enhance mission capabilities. **Scientific and technology return** can benefit us on Earth.

In-Situ Resource Utilization (ISRU)

Table 1: Main constituents of the average lunar soil according to Apollo 15 measurements [7] and principal chemical elements according to Apollo 15 and 16 data [8].

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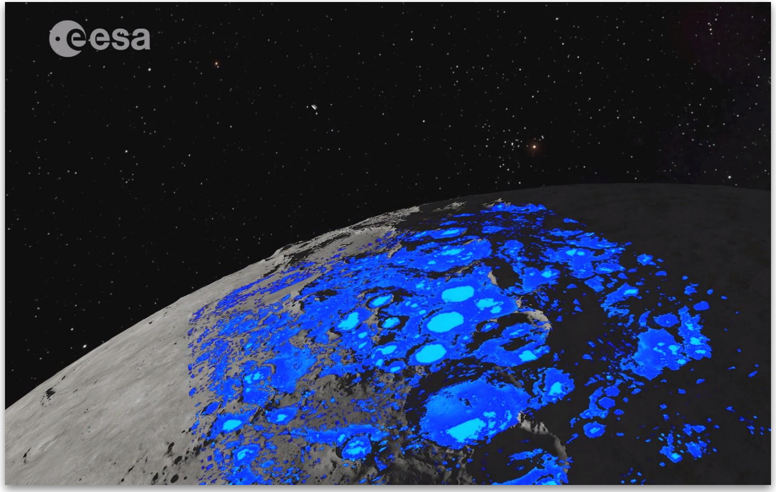
ISRU on the moon: the bright side of regolith

- Oxygen for life support and oxidizer

In-Situ Resource Utilization (ISRU)



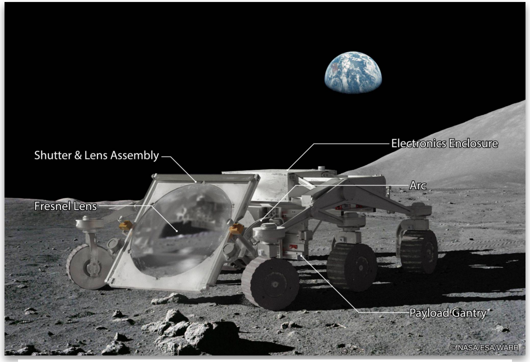
Map of possible ice water abundance on the lunar North pole © ESA

ISRU on the moon: the bright side of regolith

- Oxygen for life support and oxidizer
- Water ice for life support and hydrogen for propellant

In-Situ Resource Utilization (ISRU)

EAC-1 lunar regolith simulant sintered samples

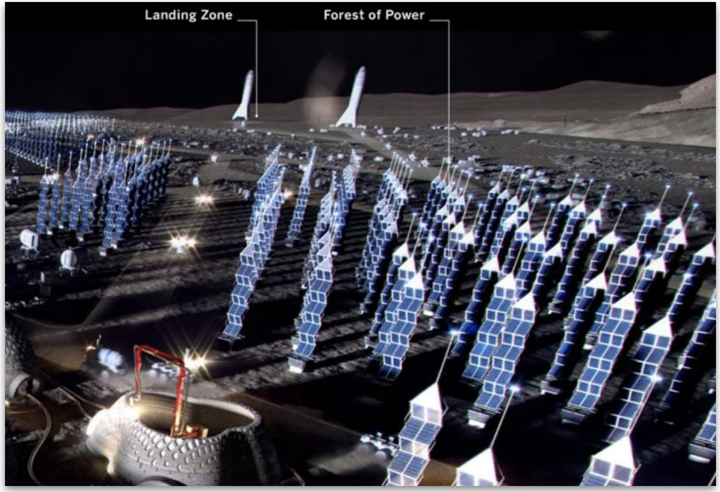


WARR Exploration rover for IGLUNA © WARR

ISRU on the moon: the bright side of regolith

- Oxygen for life support and oxidizer
- Water ice for life support and hydrogen for propellant
- Construction and infrastructure for habitats, landing pads, roadways…

In-Situ Resource Utilization (ISRU)



ISRU on the moon: the bright side of regolith

- Oxygen for life support and oxidizer
- Water ice for life support and hydrogen for propellant
- Construction and infrastructure for habitats, landing pads, roadways…
- Solar cells and more…

A R T I C L E I N F O

Keywords:
Monograin layer solar cell
Molten salt synthesis
FeS_2
In-situ resource utilization
Lunar base

A B S T R A C T

Reliable energy sources are needed in order to keep a Lunar Base on the run, and solar energy is one of the most attractive options. There are two ways to achieve it – to bring necessary solar panels from the Earth or find a way to produce them *in-situ* on the Moon from local resources. We propose the monograin layer (MGL) solar cell technology, that could be used for the *in-situ* production of solar panels on the Moon. One of the most promising compounds, that can be used as an absorber material in a monograin layer solar cell is pyrite FeS_2. There are considerable amounts of iron and sulphur in the lunar regolith. Conditions for the synthesis-growth of FeS_2

K. Kristmann, et al. (2022)

Spaceship EAC Initiative

- Advanced Manufacturing
- Energy
- Off-World Living/Crew health
- Disruptive Technologies
- Space Resources
- Robotics

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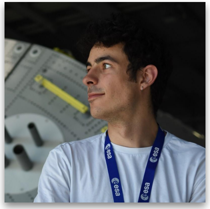
Mateo Rejón López


Joseph Chaussard

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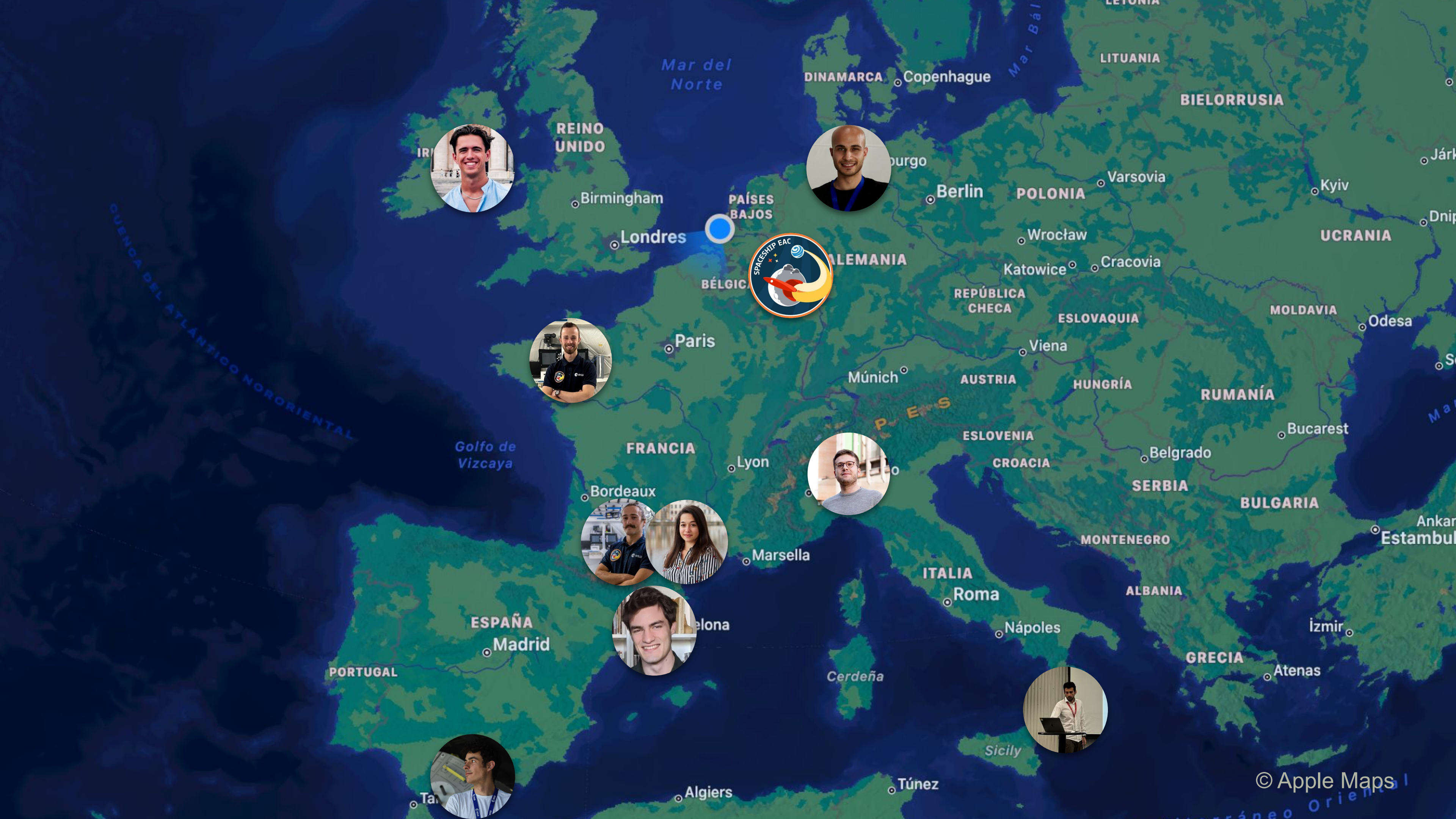
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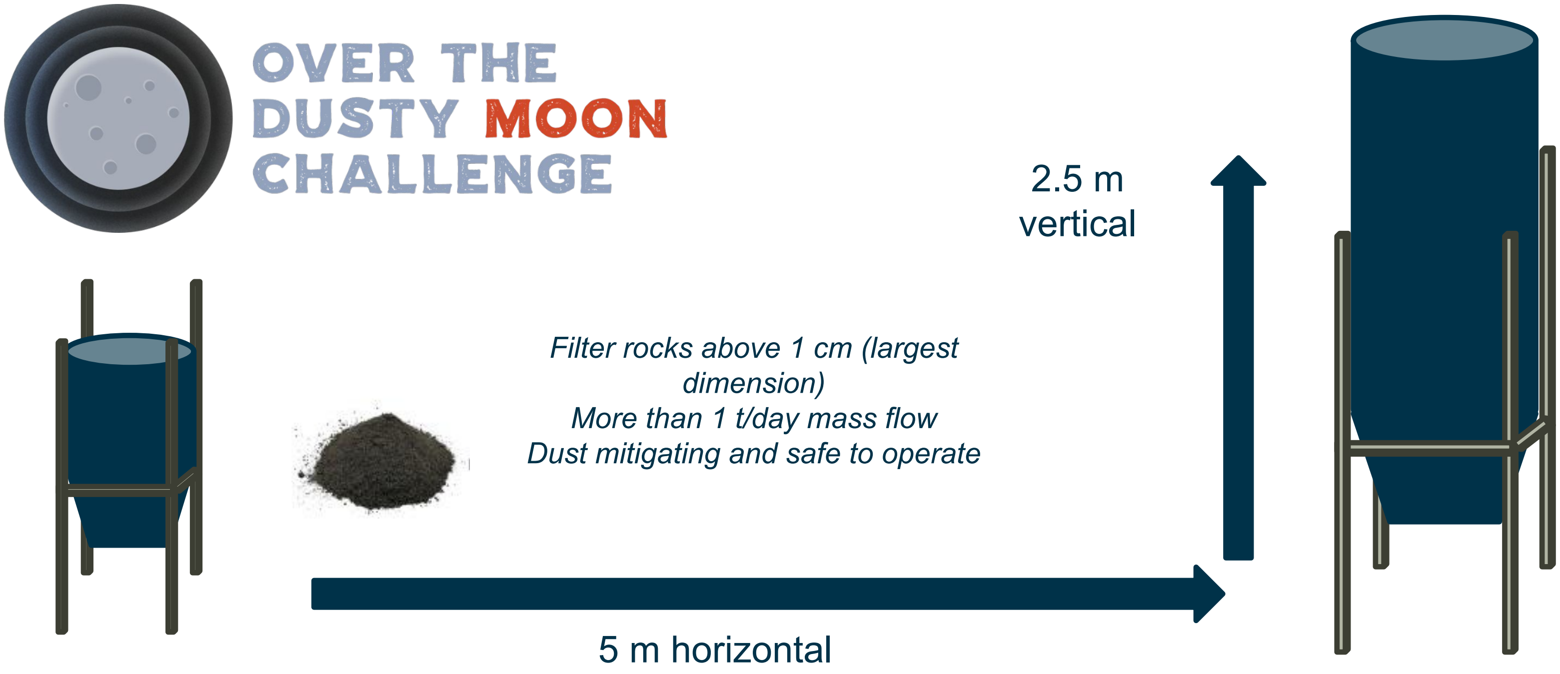
Over the Dusty Moon Challenge



Regolith transport system requirements

Special requirements

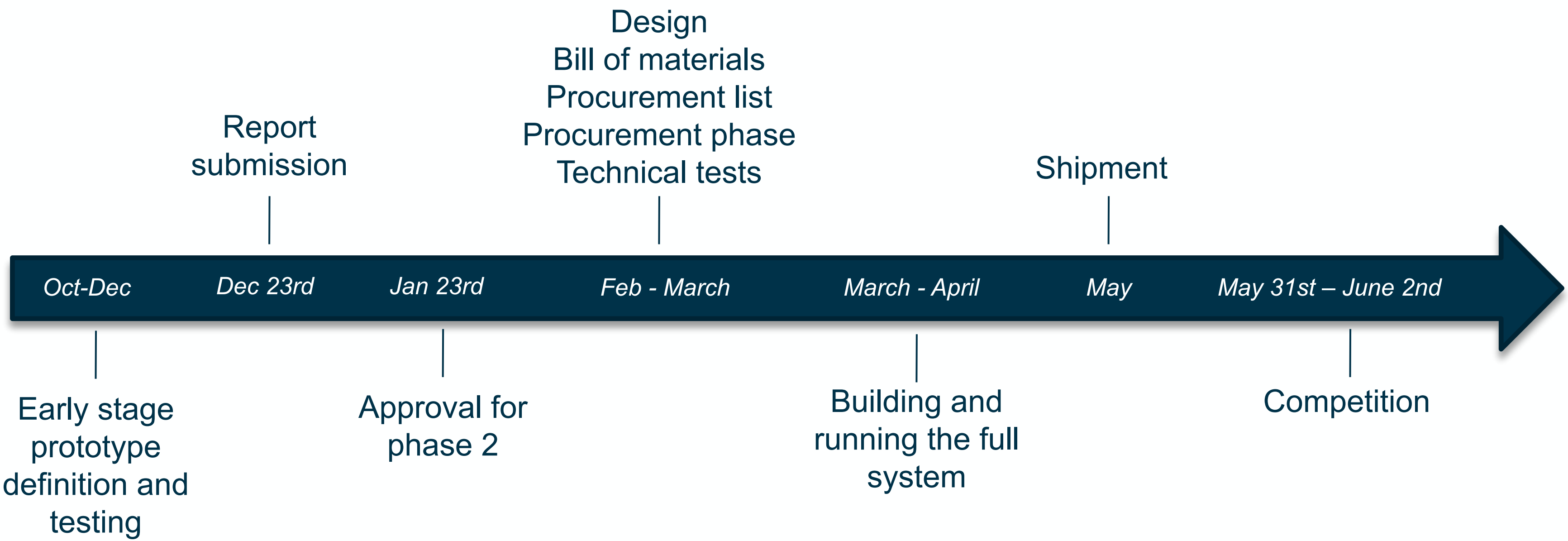
OVER THE DUSTY MOON CHALLENGE

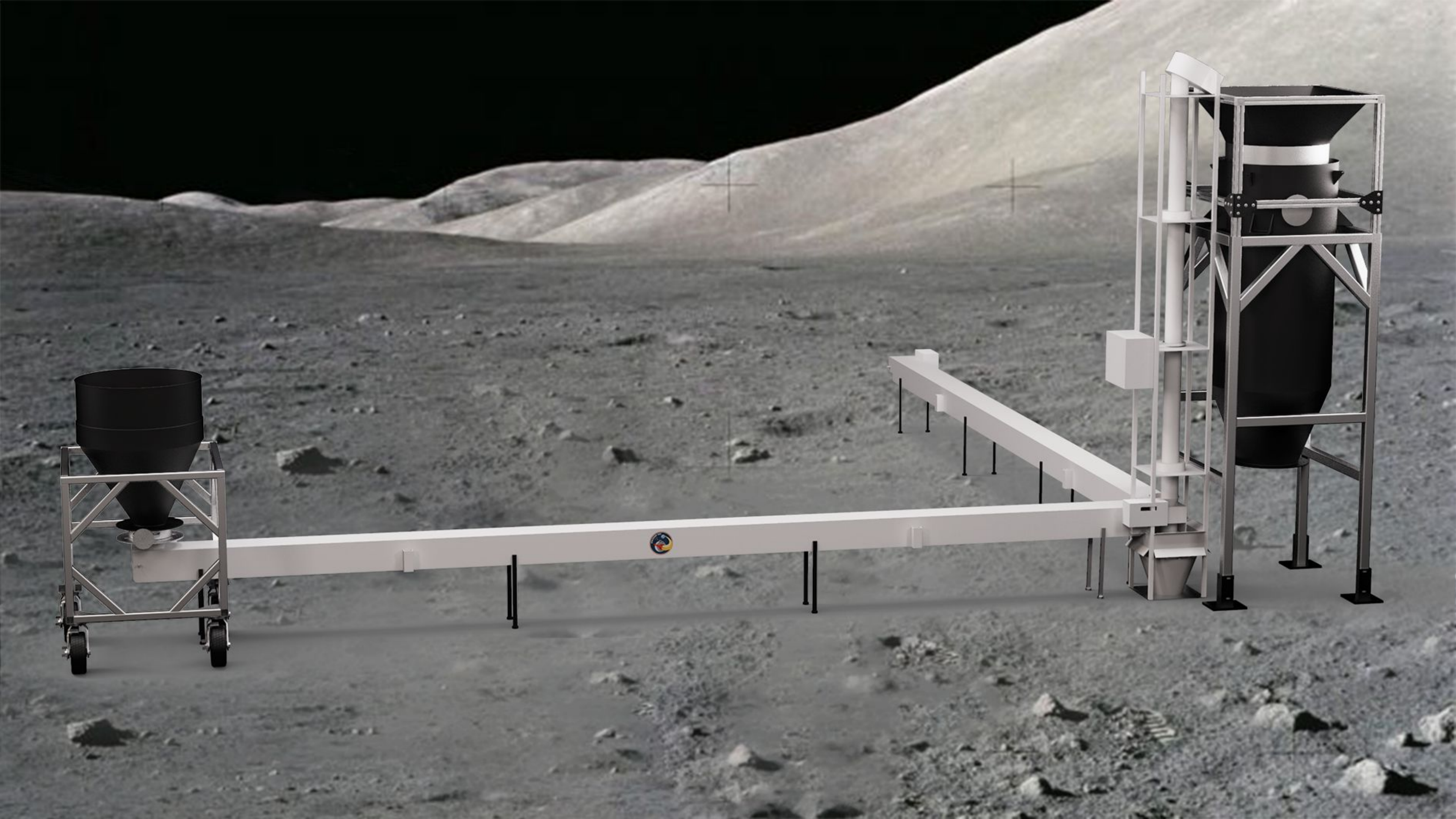
- Lightweight
- Low electrical consumption
- High mass flow

SPACESHIP EAC

- Designed to work on the moon
- Good looking structure for exhibition
- Setting the base for regolith transport activities at EAC

Challenge timeline





Vertical system: Old's Man Elevator

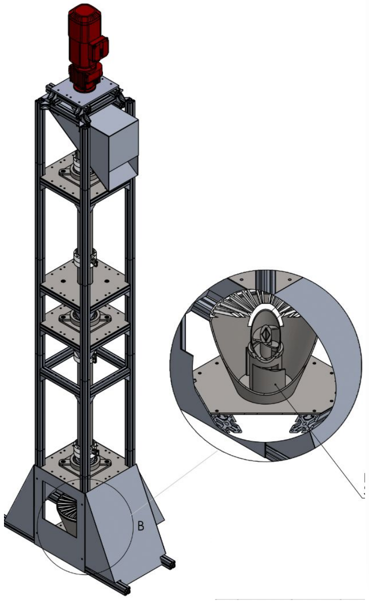
'Inverted' Archimedes' Screw:

- 3D printed screw
- External tube
- Bucket and sieving system
- Motors and ball-bearings
- Modular sections

Proved its efficiency in the industry

but

Overlooked in space applications

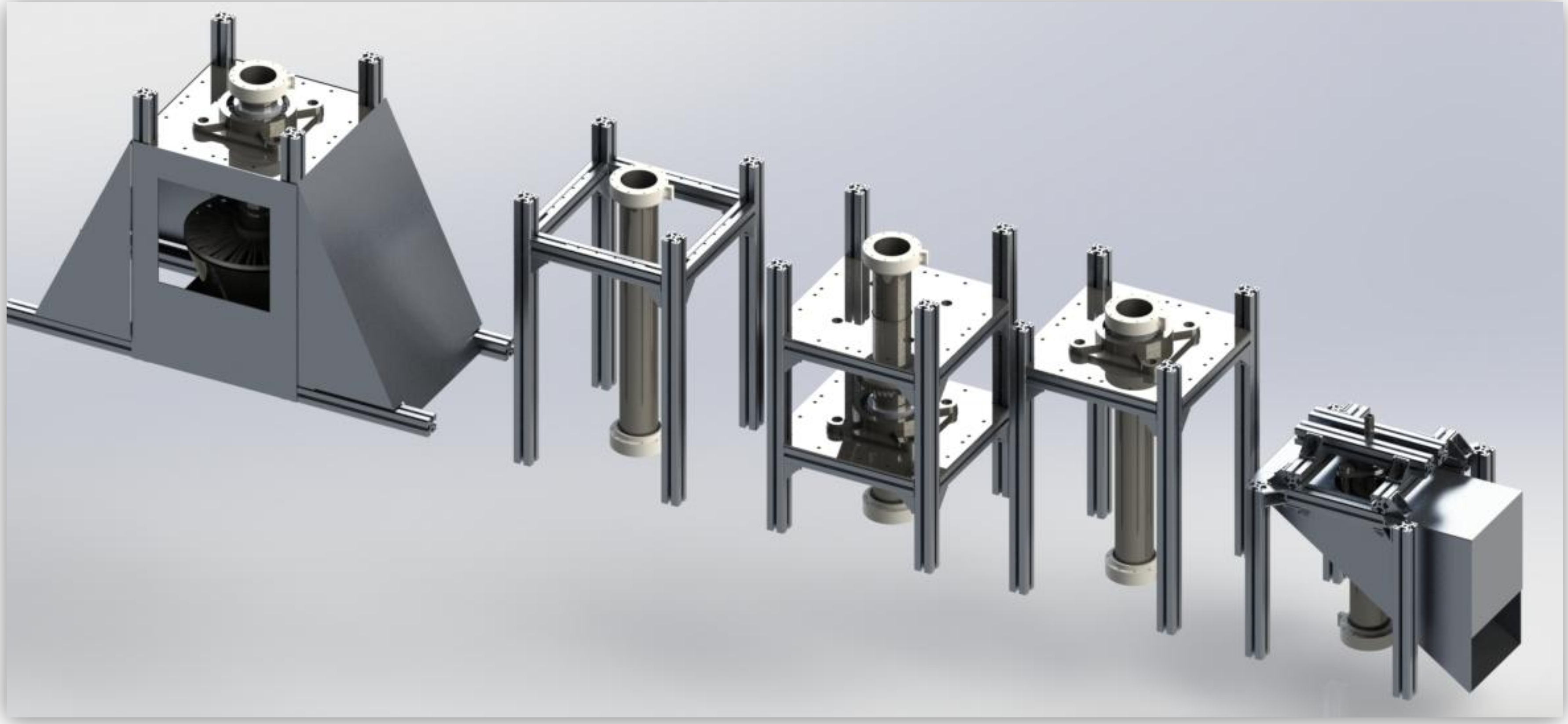


render

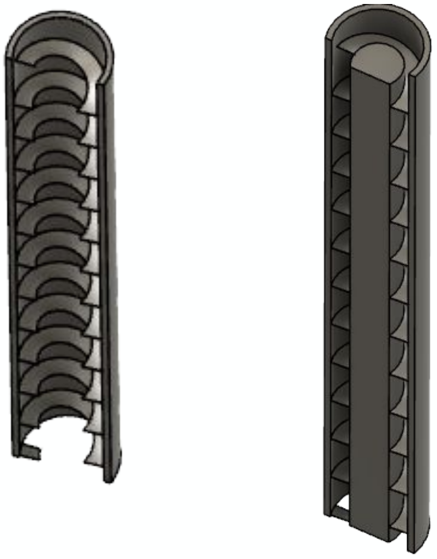
Top sections with clamps and screw

Bottom section rotating without (left) and with (right) sand and screw

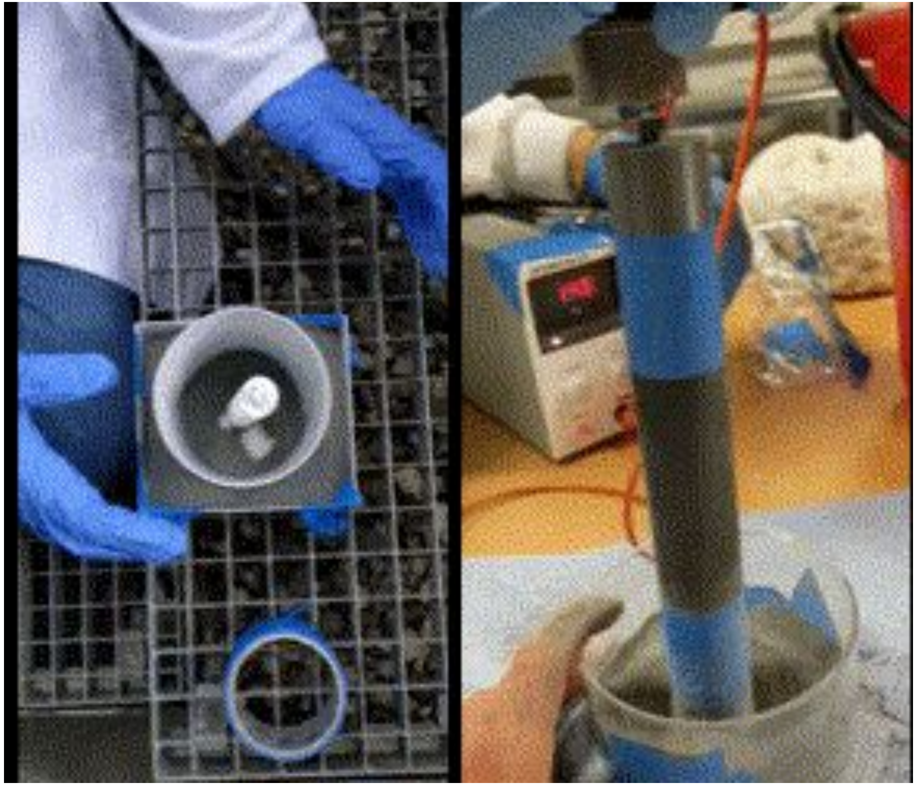
Vertical system: Old’s Man Elevator



Design selection and testing



Some rejected designs :
(left) screw threads glued to the tube
(right) screw glued to the tube

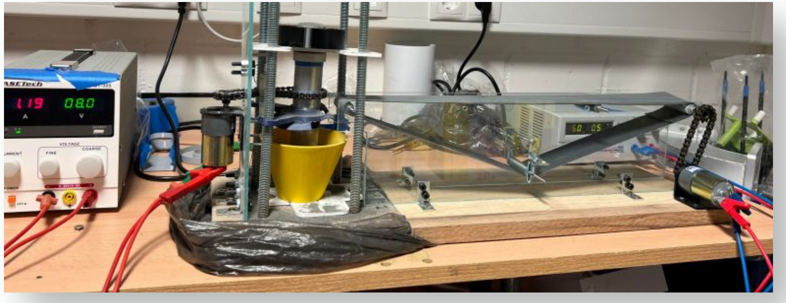


Parameters testing : diameter (left), threads spacing (right)

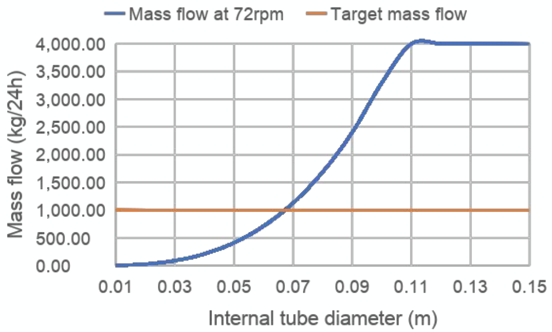
Submitted report: previous works

What was in the report :

- Prototype design and construction
- Power requirements calculations
- Mass flow analysis
- Scale-up predictions → $D_2 = D_1 \cdot \left(\frac{N_1}{N_2}\right)^{\frac{1}{3}} \cdot \left(\frac{Qv_2}{Qv_1}\right)^{\frac{1}{3}}$
- Choice of materials
- IoT implementation
- Regolith coating

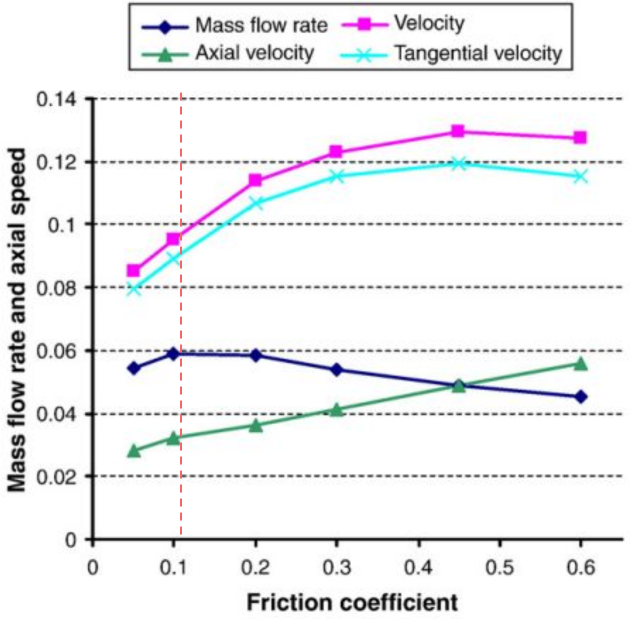


Prototype used for the report

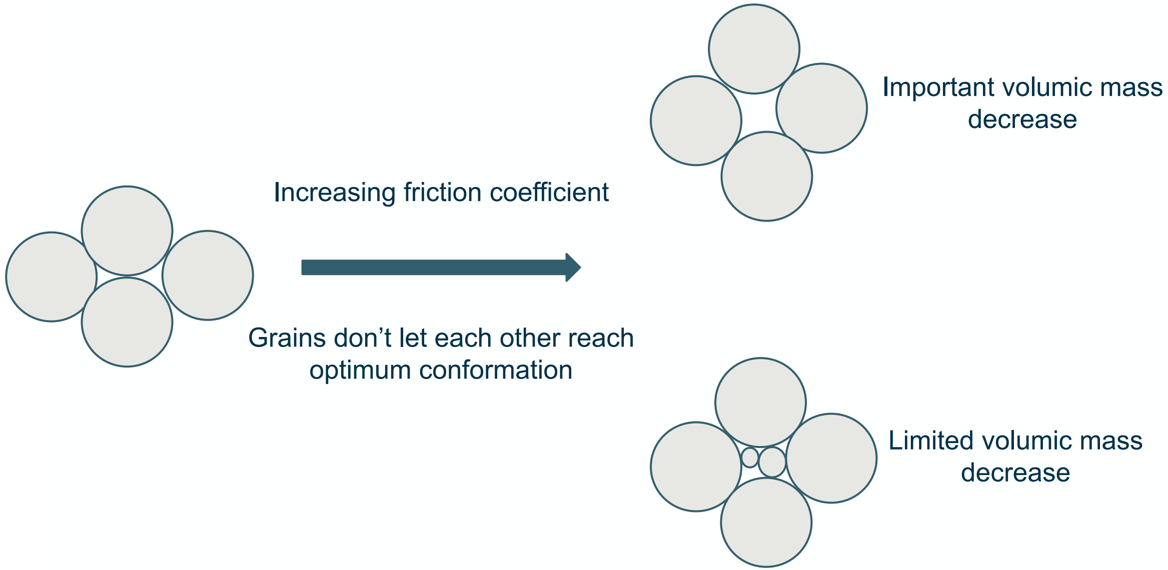


Mass flow estimation as a function of internal tube diameter

Vertical system: does it work with regolith?



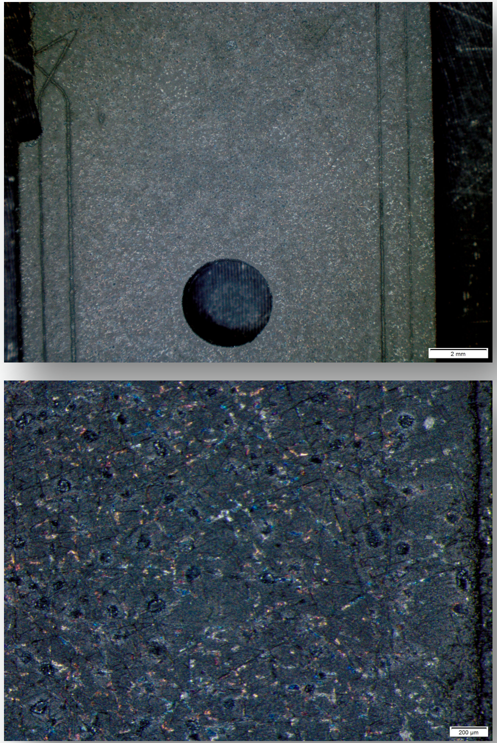
Mass flow and speed as a function of particle-particle friction coefficient (made with sorghum and wheat grains)



McBride, W., et P.W. Cleary. « An Investigation and Optimization of the 'OLDS' Elevator Using Discrete Element Modeling ». *Powder Technology* 193, nº 3 (août 2009): 216-34. https://doi.org/10.1016/j.powtec.2009.03.014.

Regolith coating

Aluminum tube after 1h of use

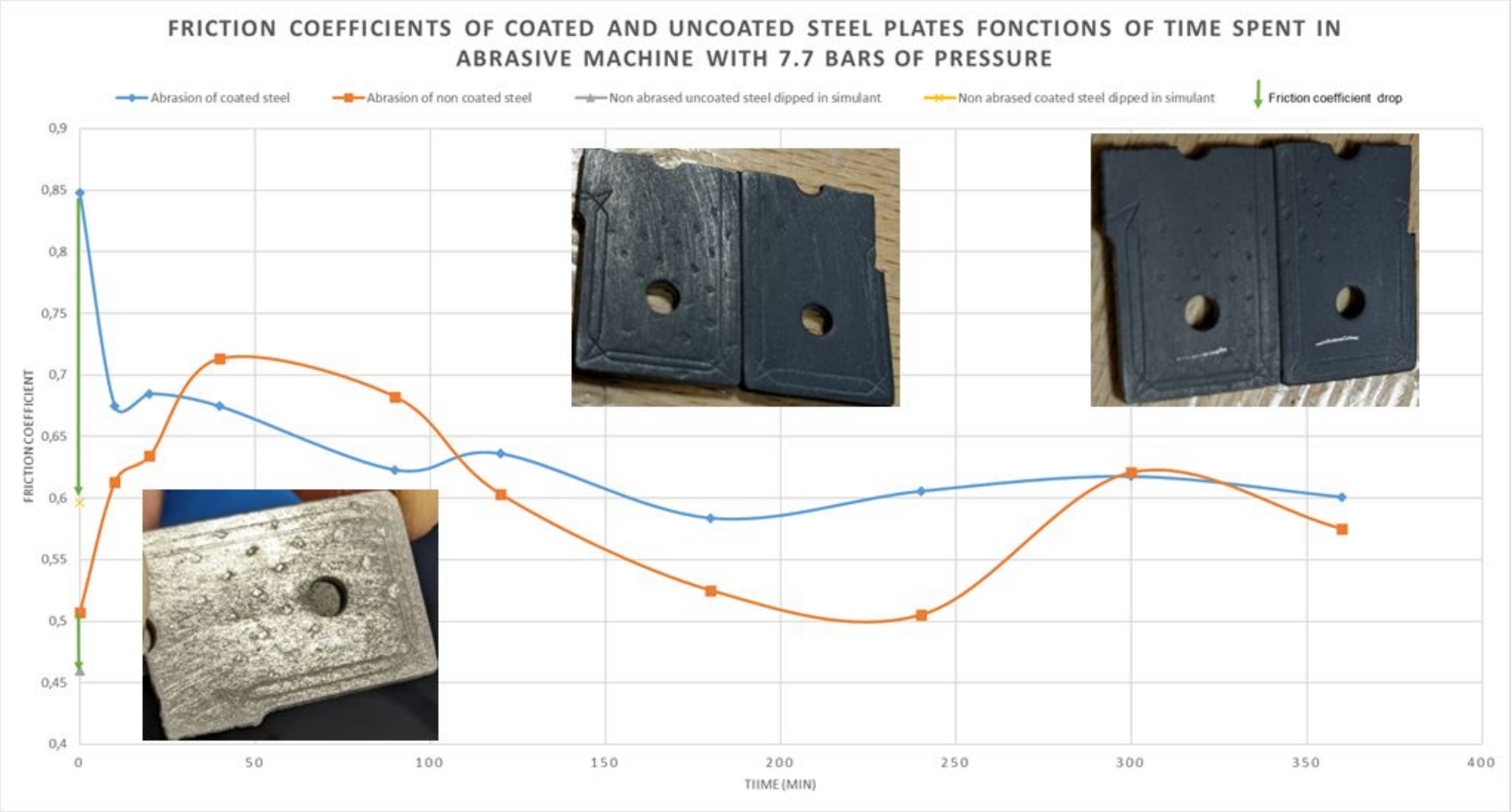


Stainless steel coupon coated once

How does it affect:
- **Friction**
- **Wear resistance**

Coated cast iron tube

Regolith coating



The sieving system

Rotating sieve (left)
Bottom section after competing (right)

Using centrifugal force for sieving :

- Efficient on earth starting a given speed
- Avoiding clumps of electrostatically charged regolith

How to assess the effectiveness of the sieving system during the challenge?

Horizontal system: Conveyor Belt

The technology :

- Used in the mining industry

- Convey heavy material over long distances

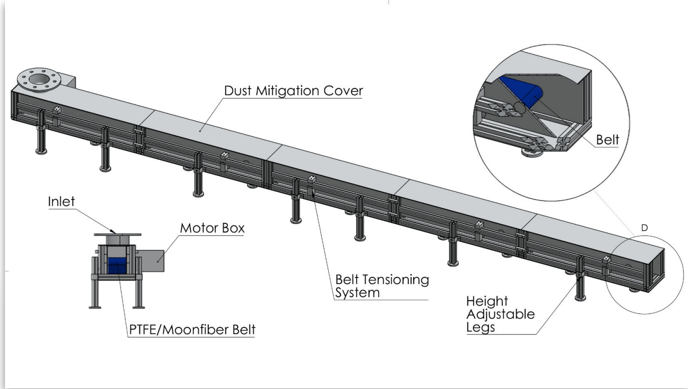
Our system:

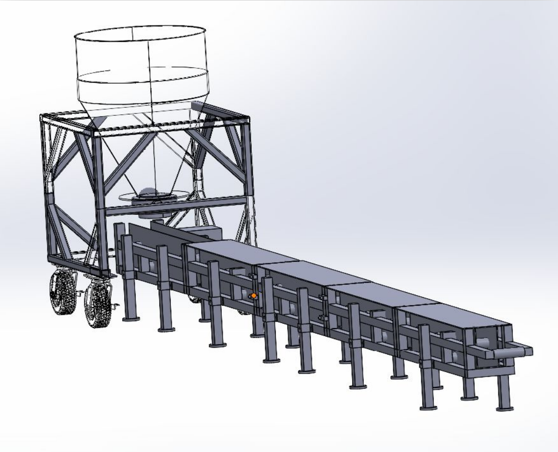
- ITEM profiles for the structure

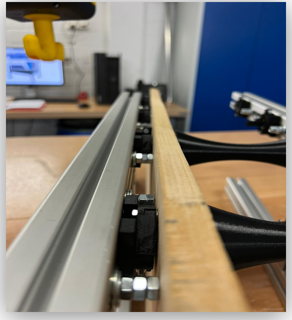
- 5 m Teflon conveyor belt

- 5x1 m sections for portability

- Motors and ball-bearings





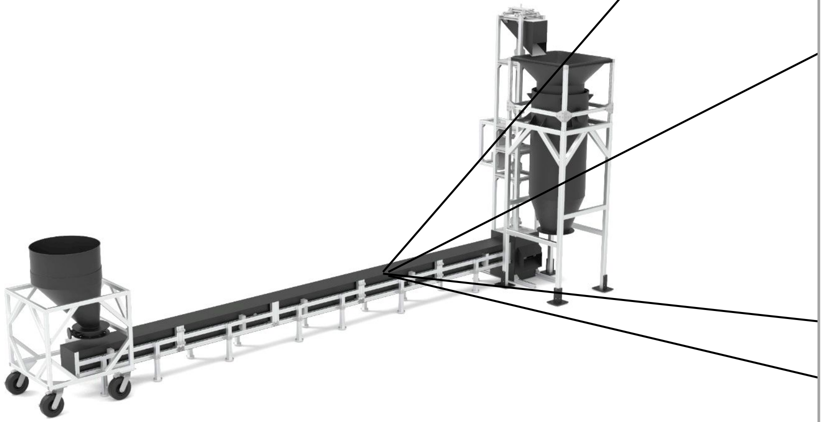


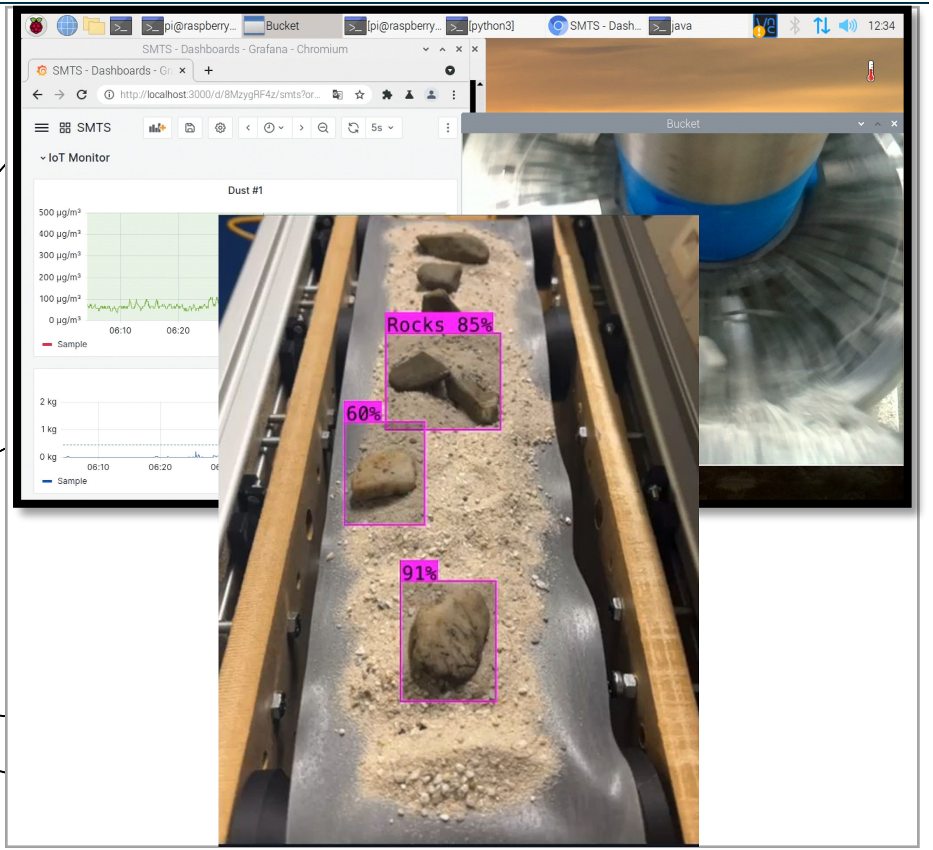
Horizontal system render and first prototype

Automation of lunar regolith transportation

IoT applied to our system :

- Dust mitigation **control**
- Mass flow **measurements**
- Rocks **detection**
- Speed **synchronization**





Render and IoT system screenshot

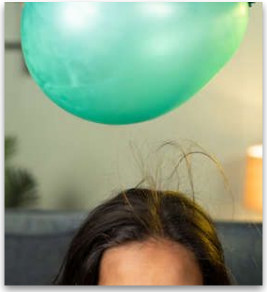
Is it fit for the moon in the end?

Regolith rheology is not yet understood and intergranular friction **causes triboelectric charging**

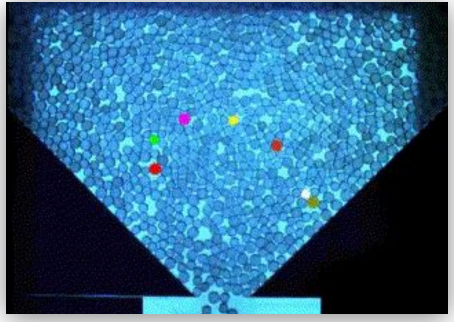
Our system jams the regolith before conveying it: **avoids uncertainty** due to charging and unconventional flowing behaviour.

High friction coefficient between wall and jammed material benefits mass flow efficiency

Transforming regolith's high abrasiveness into a **positive side effect**.



Static electricity:
balloon and hair exemple



Granular Jamming in a hopper

ang, J., et R. P. Behringer. « How Granular Materials Jam in a Hopper ». *Chaos: An Interdisciplinary Journal of Nonlinear Science* 21, n° 4 (1 décembre 2011): 041107. https://doi.org/10.1063/1.3669495.

Over the Dusty Moon Challenge

SpaceTeam AGH
60 Kg
1st place

UNSW Aussienauts
20 Kg
2nd place

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Over the Dusty Moon Challenge

The rock hoppers
>1Kg
5th place

Spaceship EAC
60Kg
3rd place

MoonAixperts
2Kg
4th place

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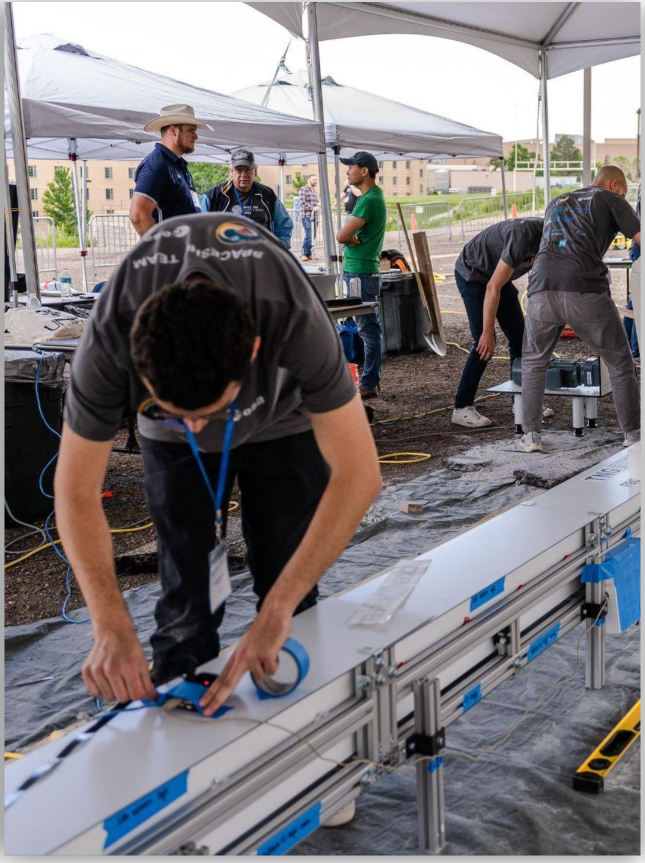

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Thank you!