EXCAVATION OF PLANETARY REGOLITH IN NON-EASILY ACCESSIBLE PLACES USING WIRELINE TECHNOLOGY

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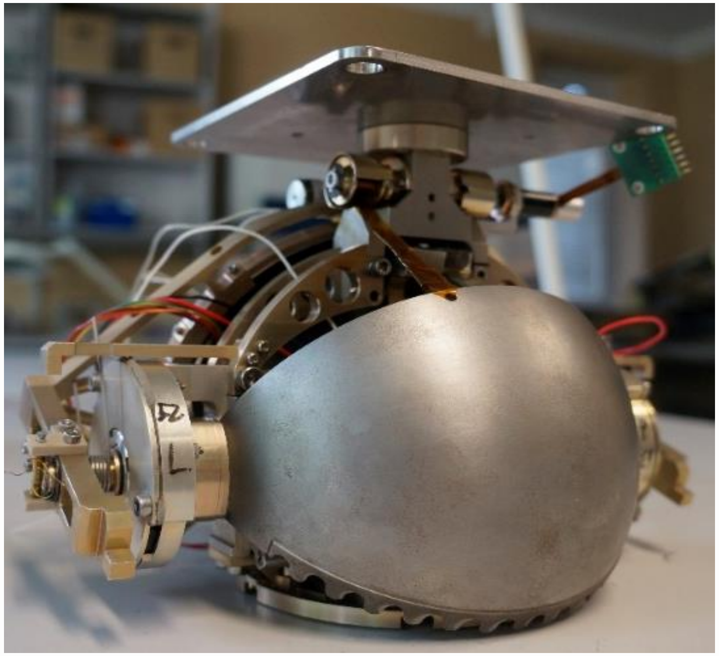
Outline

1. CBK previous experience with planetary subsurface investigations and gravity impact on its design,
2. Concept of a excavation in non-easily accessible places,
3. Status of two technologies development:

   - PACKMOON device

   - Drill string, tubular booms

4. Conclusions and Future plans

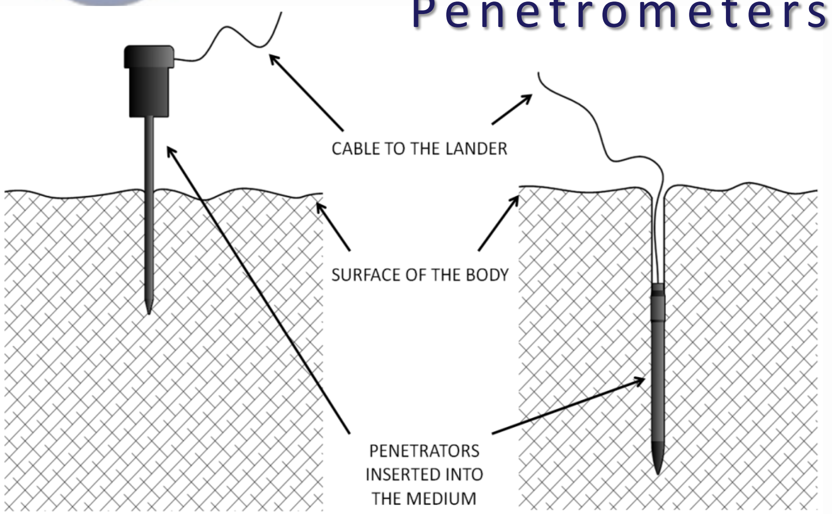


Introduction

- Sampling and excavation devices are technical solution allowing to realize main function: to collect regolith
- The difference between them is related to the scale of operation. Sampling systems acquire grams of regolith whereas excavation systems operates with kilos or tons
- The Space Research Center (CBK PAN) at the Polish Academy of Sciences has developed two technologies related to sampling systems:
  - a drill string based on a tubular boom
  - a sampling device, called PACKMOON.
- Due to gap of funds for increasing TRL level of these technologies I focused during last year on concepts of scaling up to be applicable for ISRU

CBK PAN past expirience

Penetrometers and sampling devices



Theoretical description is provided in Seweryn et al., Acta Astronautica 99, 2014

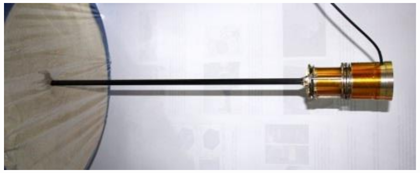
CBK PAN / Astronika contribution to HP^3 on NASA Insight mission

Low Velocity Penetrators

MUPUS

Mole „KRET”

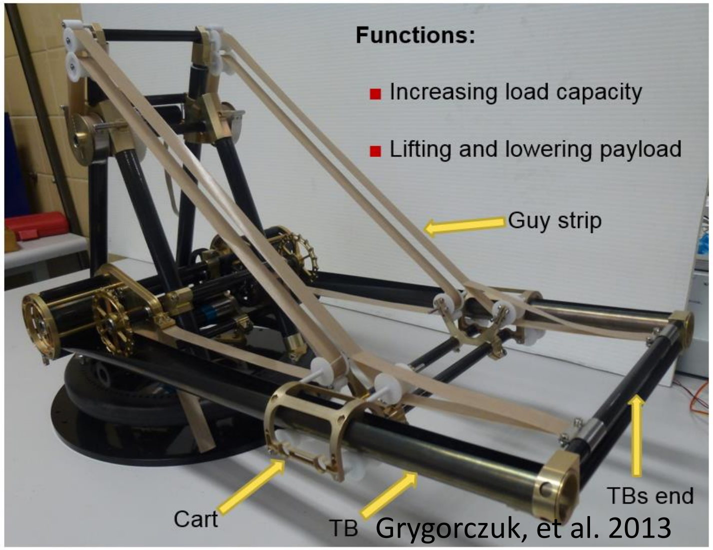
„CHOMIK”

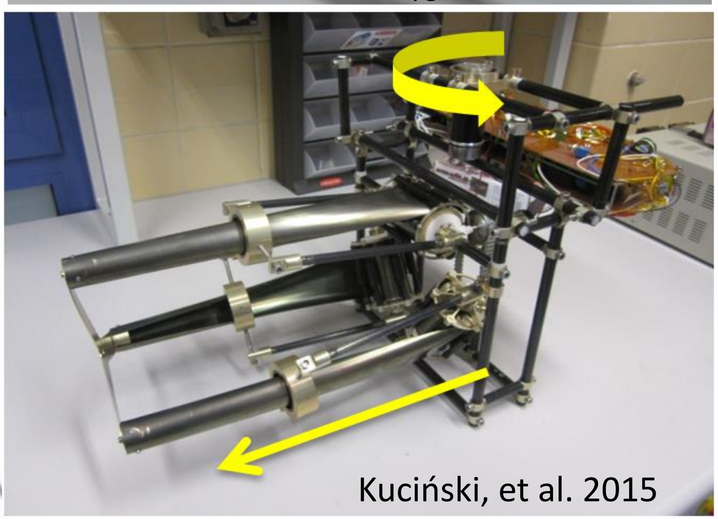


HEEP

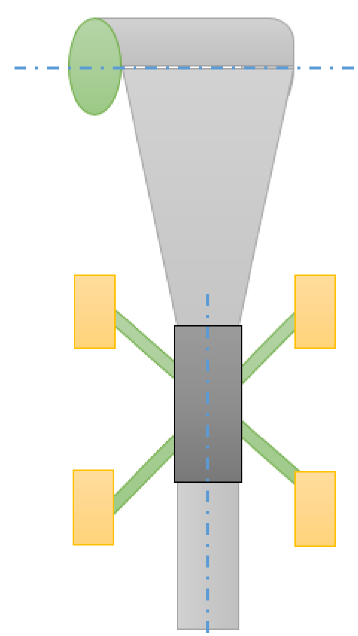
Source: POLSA, 2014

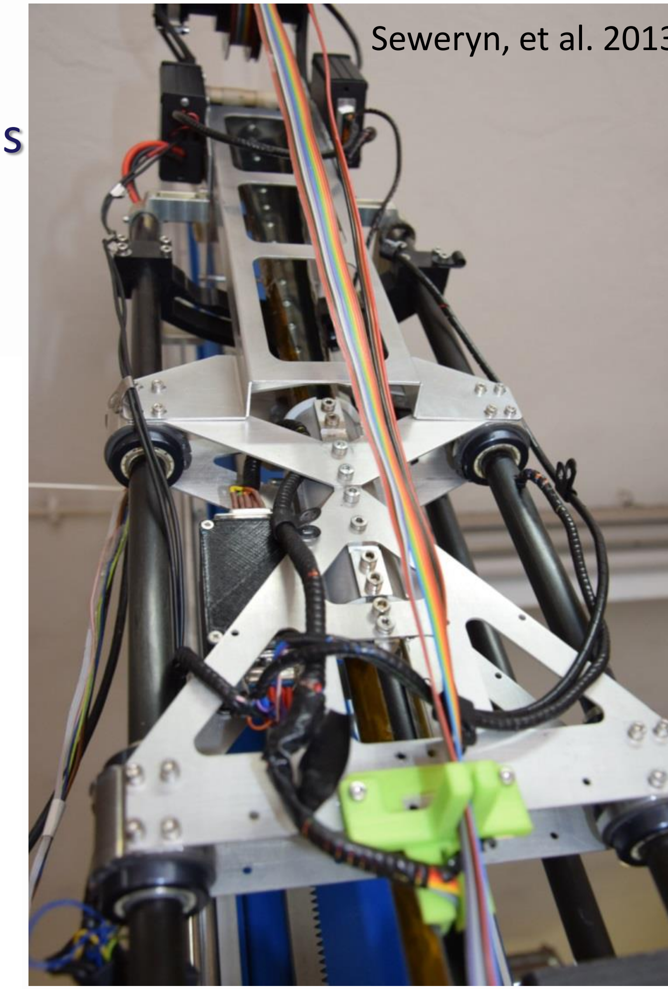
CBK PAN past expirience





Tubular booms



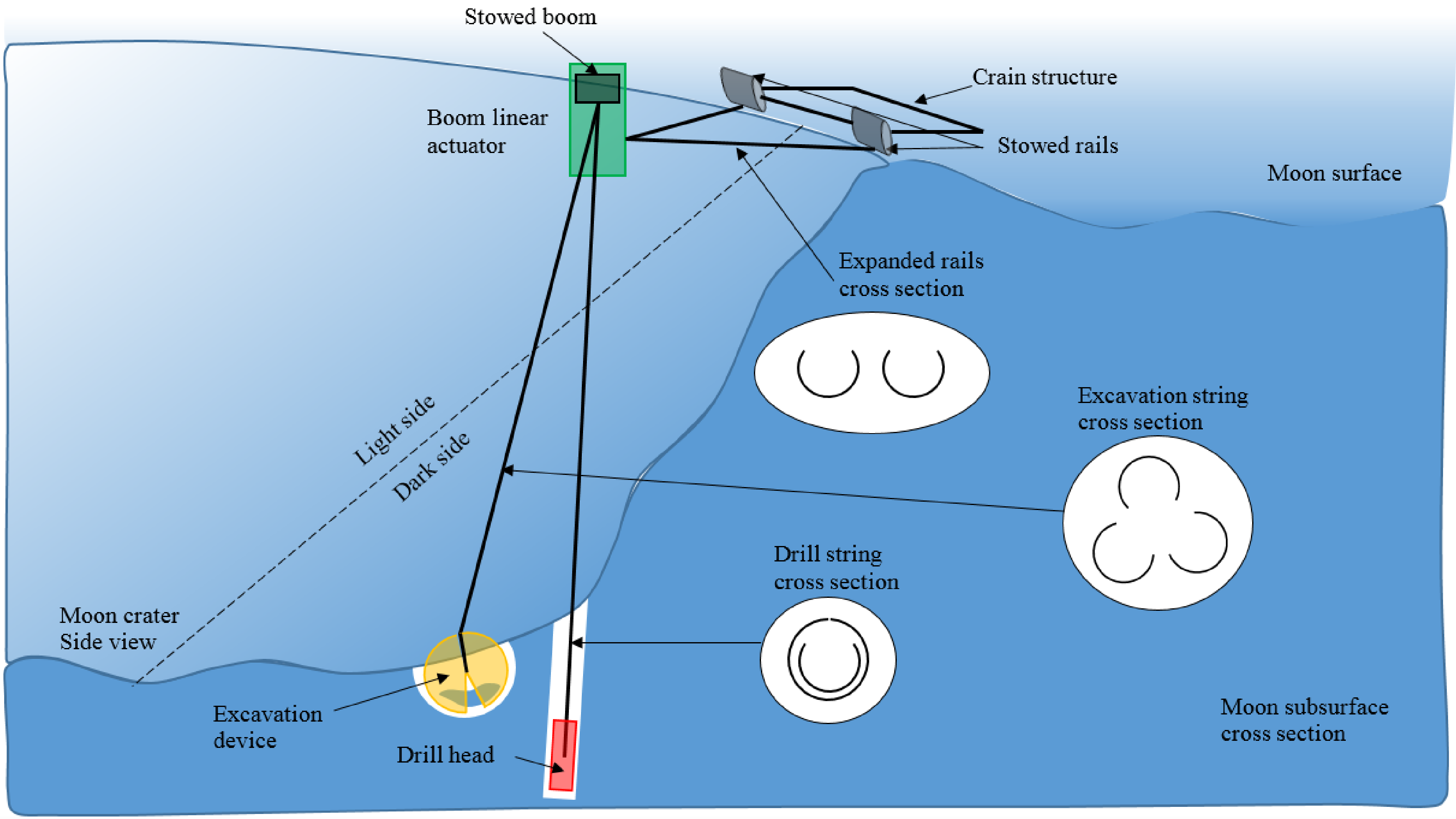


Concept of a excavation in non-easily accessible places

Excavation

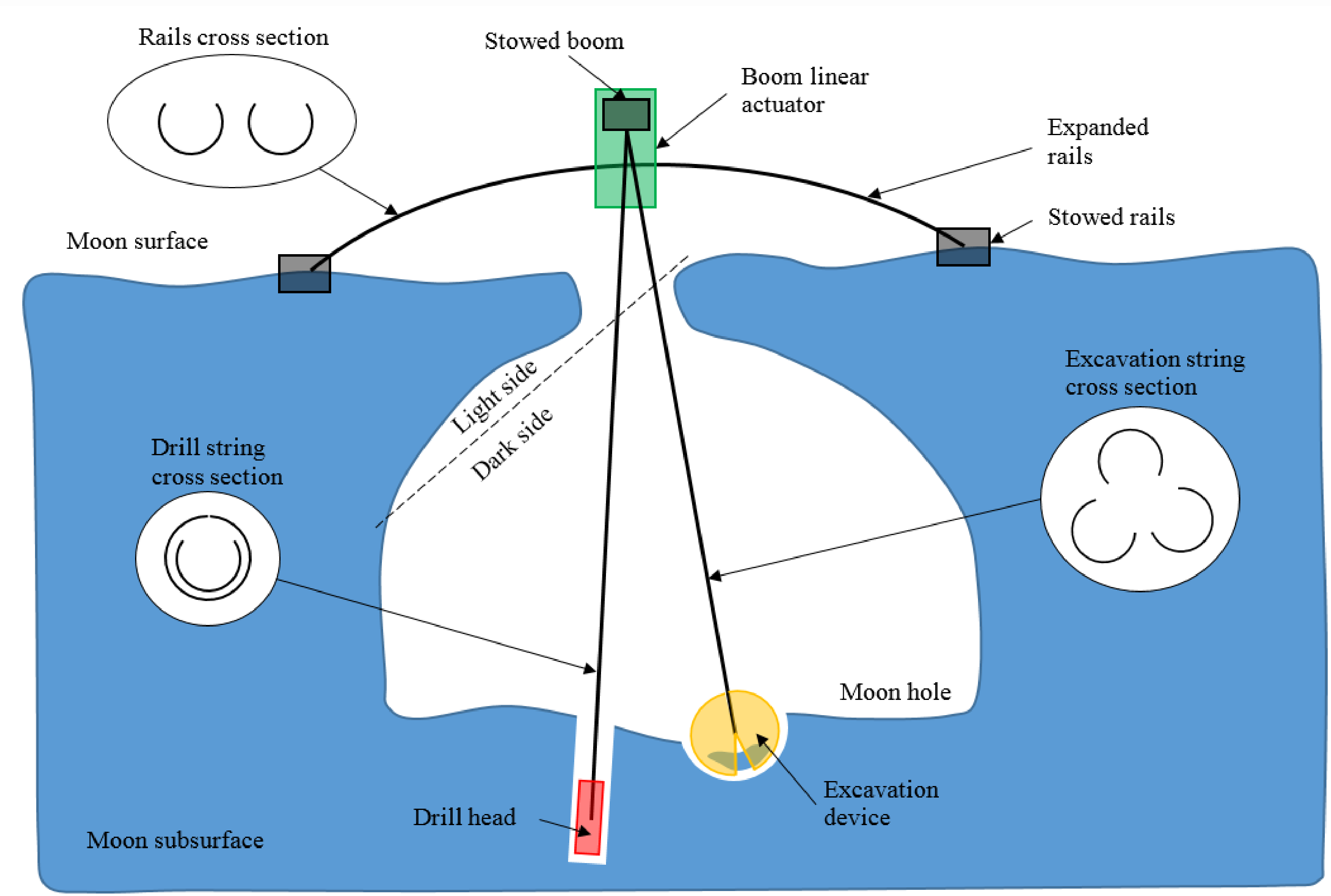
- The excavation scenario was prepared with assumption that the most valuable resources (ice) are in non-easily accessible paces on Moon such as Moon hole or Moon crater.
- The scenario utilize the drilling wireline technology (Zacny et al., 2013)
- The prospecting head might be a drilling device (Seweryn et al 2014) able to collect a core's for further analysis.
- The excavation head might based on Packmoon sampling device (Seweryn, 2016) scale up to version able to collect hundreds of kilos of regolith
- Deployments and drill strings based on tubular boom technologies (Grygorczuk et al 2013, Kuciński et al. 2015)

Excavation



Stowed boom
Crain structure
Boom linear actuator
Stowed rails
Moon surface
Expanded rails cross section
Excavation string cross section
Light side
Dark side
Drill string cross section
Moon crater Side view
Moon subsurface cross section
Excavation device
Drill head

Excavation

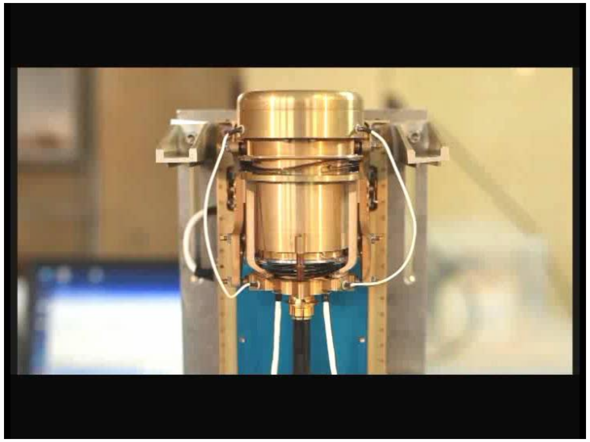


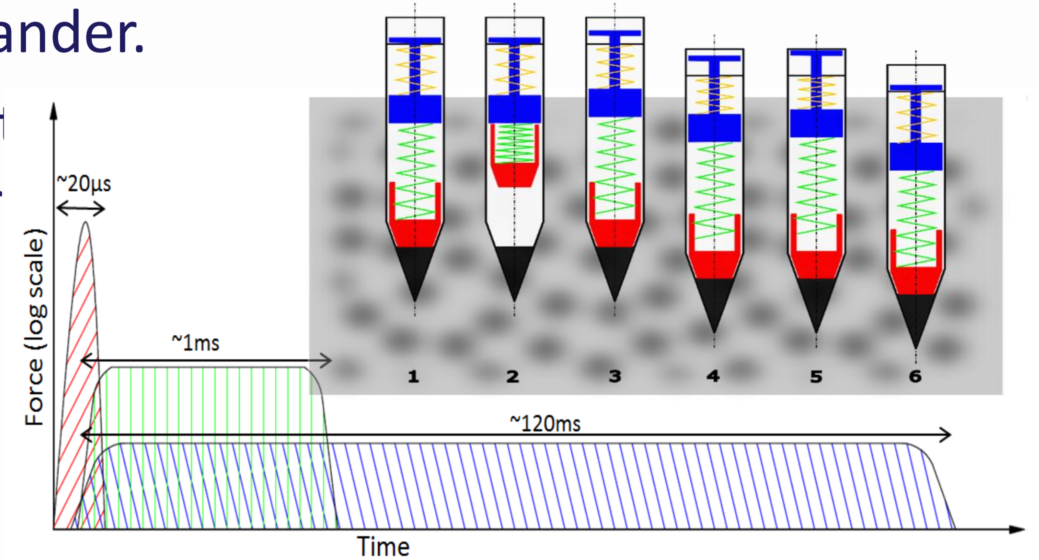
Rails cross section
Stowed boom
Boom linear actuator
Expanded rails
Stowed rails
Moon surface
Light side
Dark side
Excavation string cross section
Drill string cross section
Moon hole
Excavation device
Drill head
Moon subsurface

PACKMOON prototype

Main drivers for a PACKMOON development

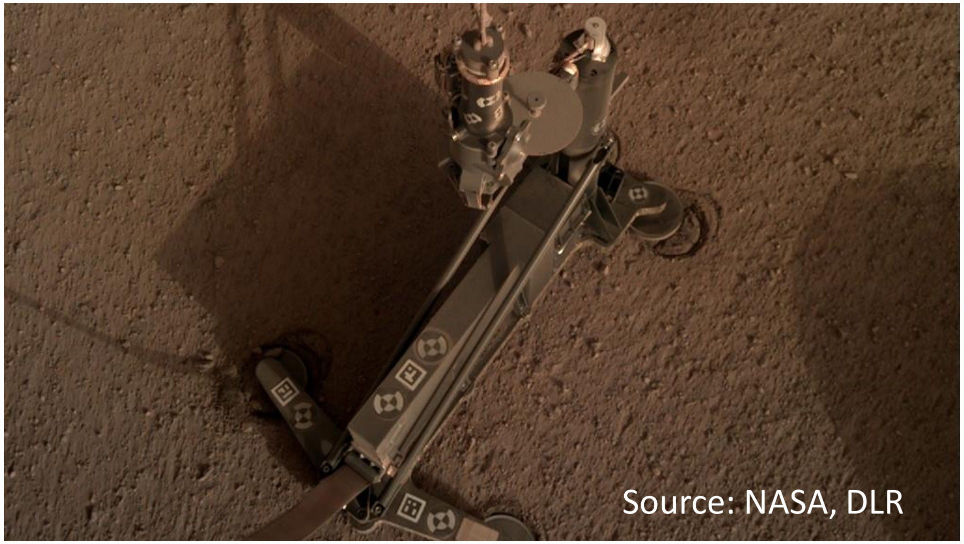
- High amplitude dynamic force is the effective way to pump energy into the end of crack and in that sense it seems to be well applicable for sampling process in a priori unknown space environment.
- For safety reasons, the sampling tool must not anchor the lander.
- The sampling tool must not disturb the sample interior structure.
- The sample tool should allow for multiple use

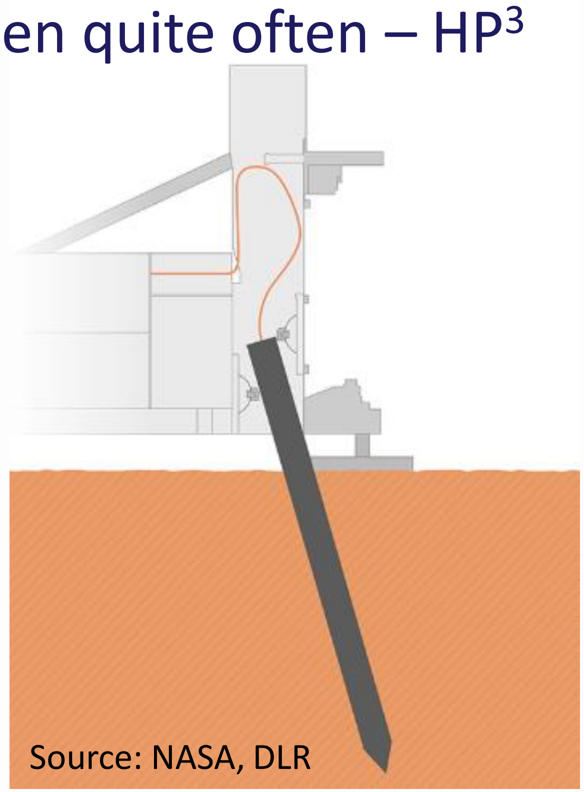




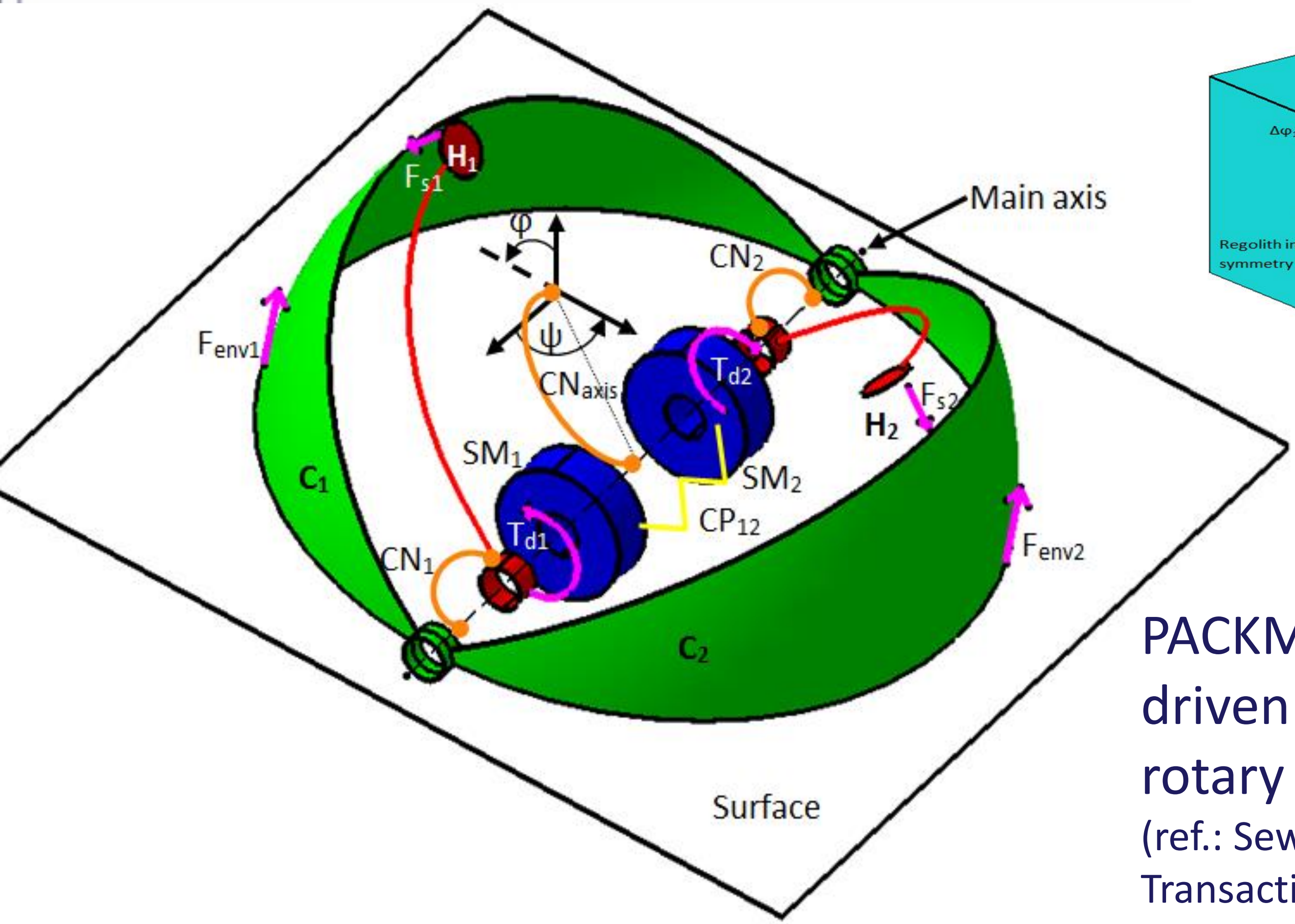
Main drivers for a PACKMOON development

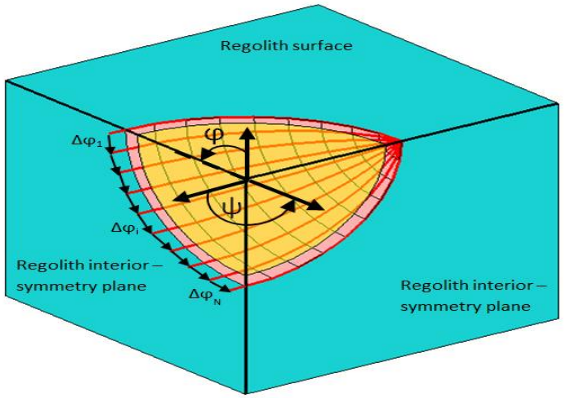
- For safety reasons, the sampling tool must not anchor the lander.
- The failure handling (which may happen quite often – HP^3 example below) is important





PACKMOON concept



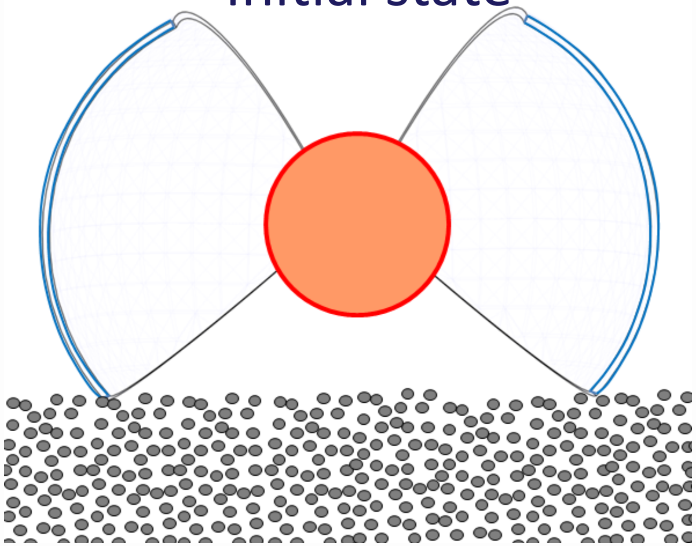


PACKMOON device driven by hammering rotary action

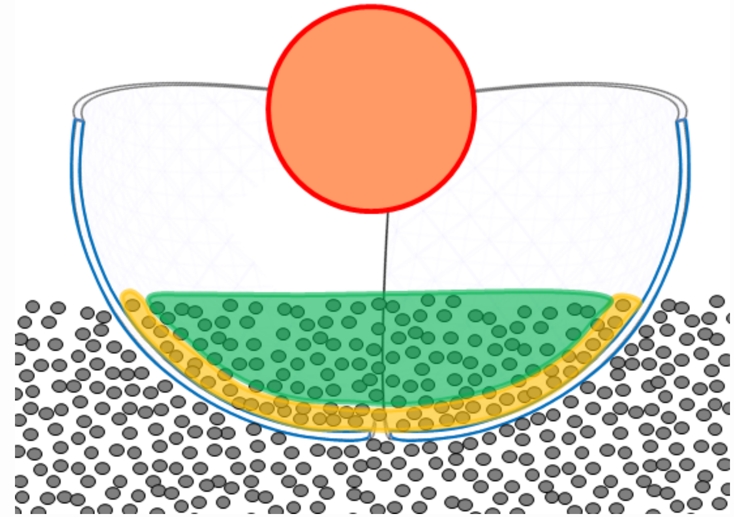
(ref.: Seweryn K., ASME/IEEE Transactions on Mechatronics; Vol. 21, No. 5, 2016)

Impact on sample

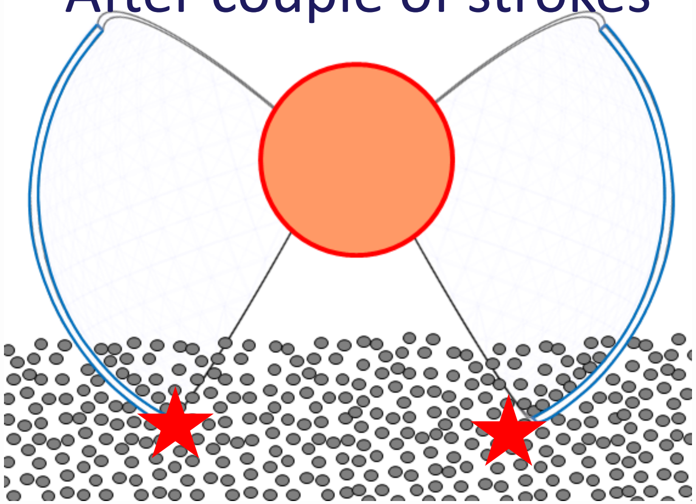
Initial state



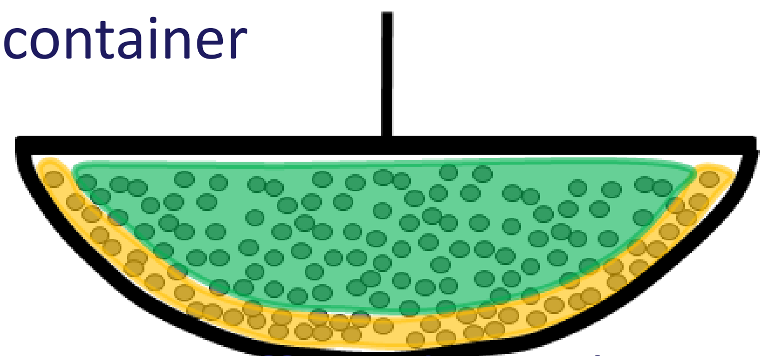
Final state



After couple of strokes



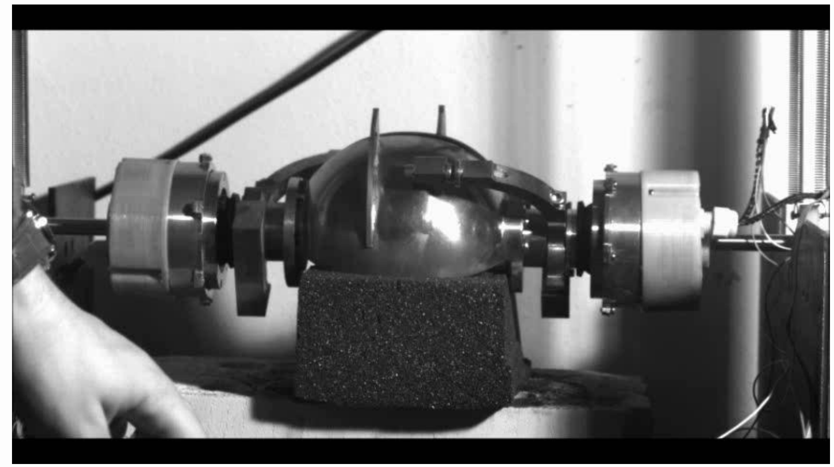
Sample delivery to container



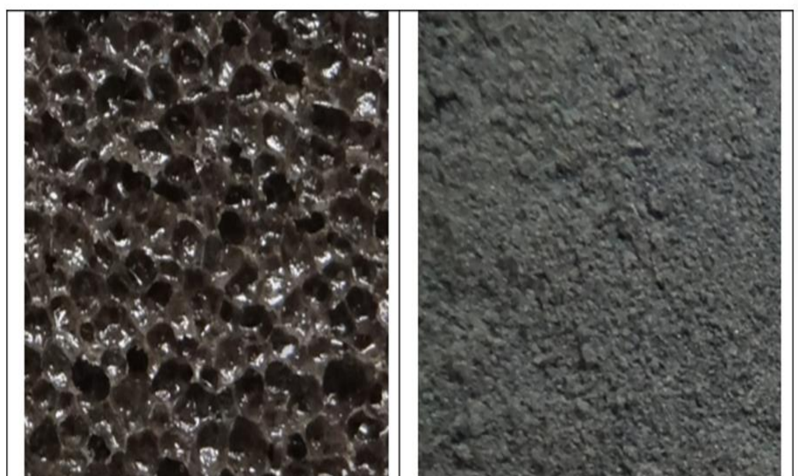
Green – not affected sample

Yellow – partially affected sample

First and second breadboard



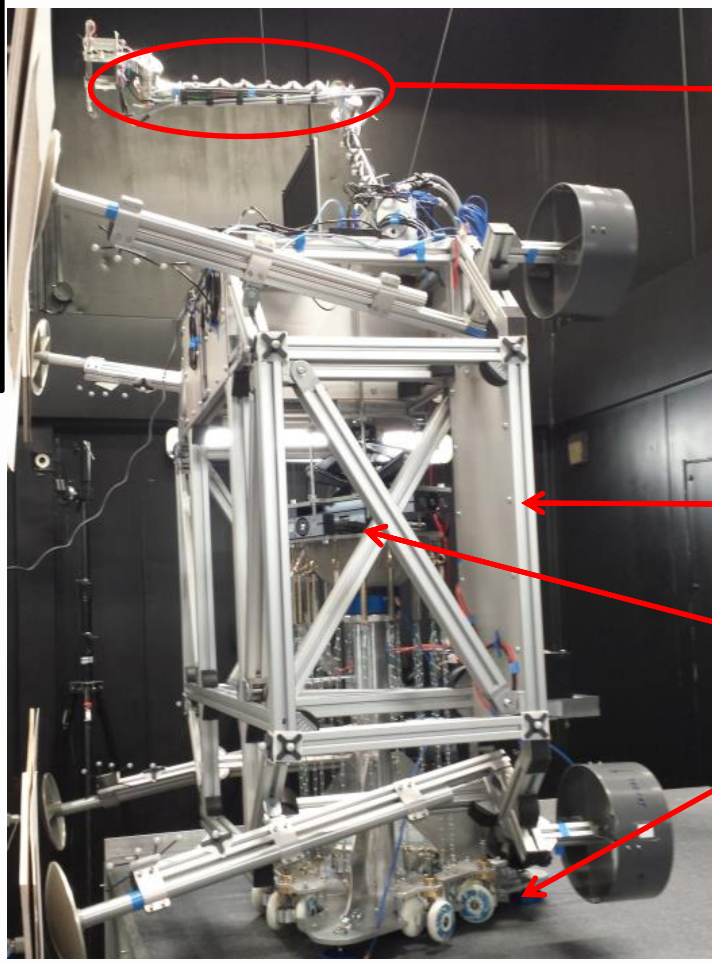
Materials sampled during tests ref. Seweryn K., et al., PSS, 2014

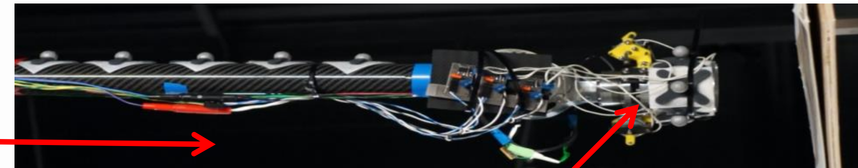


Low gravity sampling

Activity funded by ESA SAMPLER project led by Airbus UK with AVS, Selex, Open univ and Frentech involvment

Artificial Phobos surface



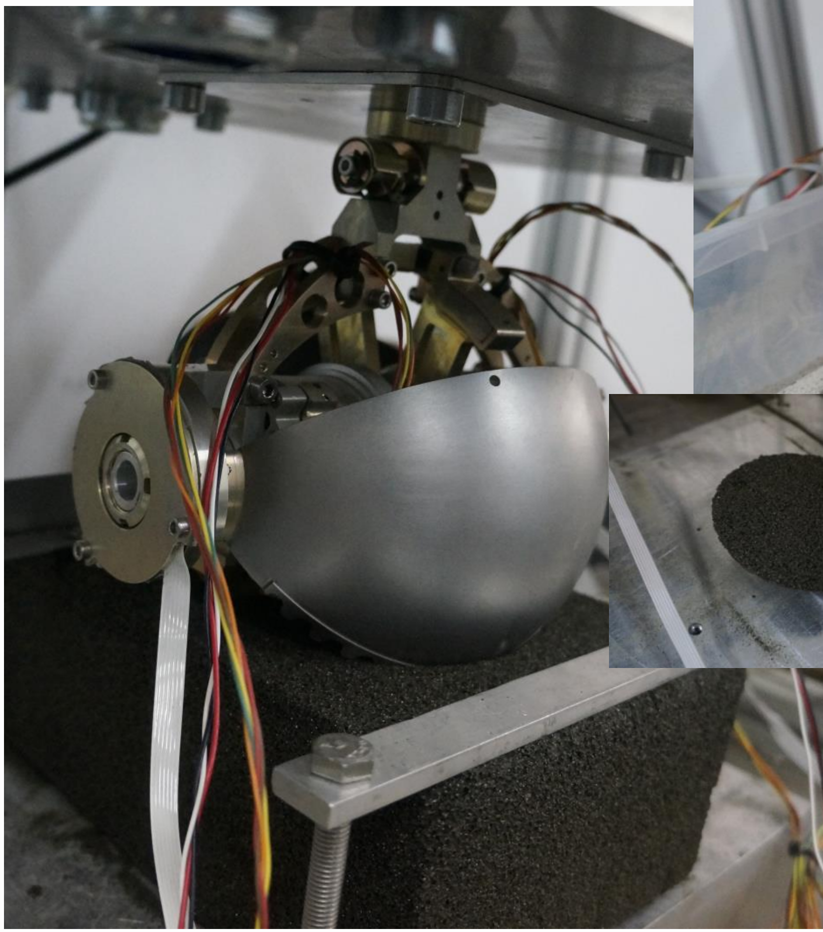


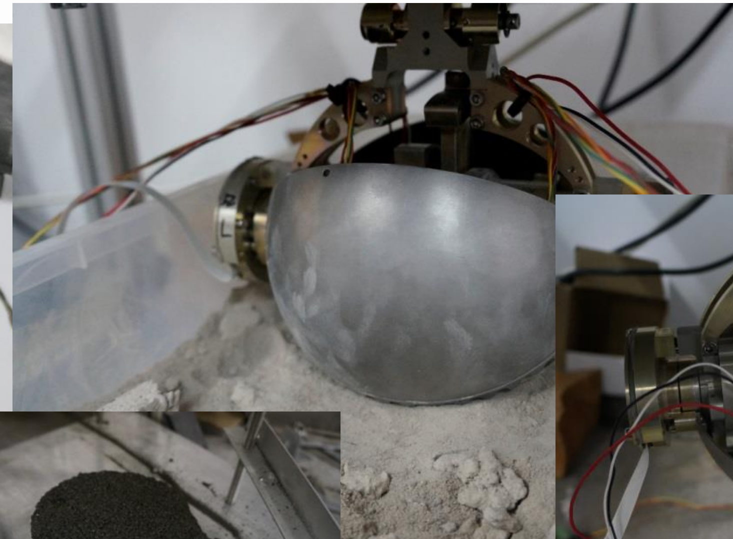
Robotic arm with Packmoon emulator

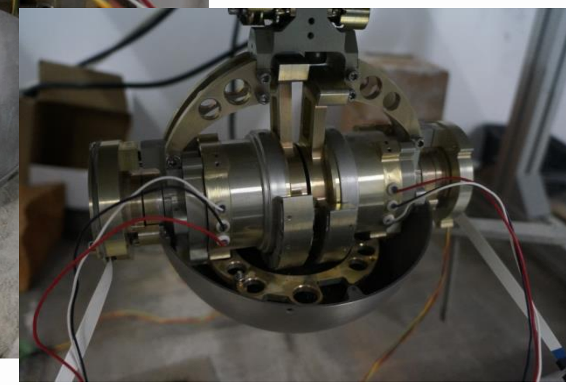
Lander equipped with thruster moving on:
- spherical air bearing
- flat air –bearings

Air-bearing testing facility

Tests done in Lunar regolith and foamglass







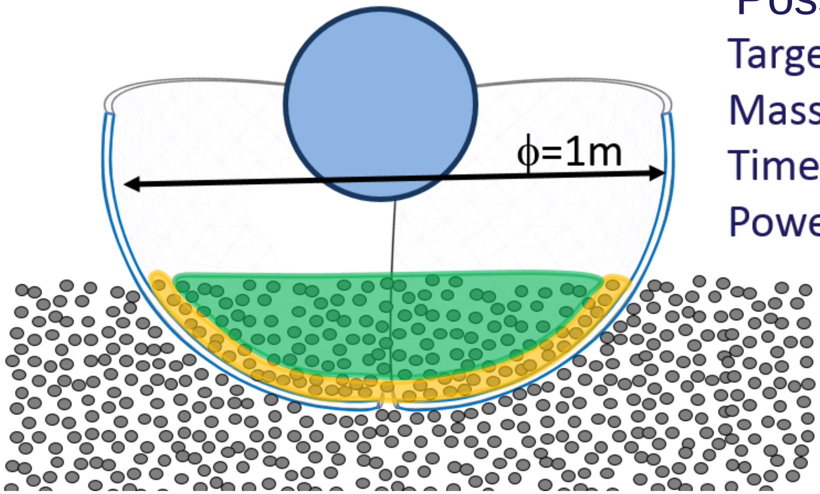
Parameter	Value
Mass	2.7kg
Volume (sample container)	150 cm^3
Dimensions of sample container	Φ124mm x 40mm
Hammering energy	< 2J
Sampling Time	< 10min

Tests Results

Material	Strikes	Time [s]	Mass [g]	Strikes (mean)	Time [s] (mean)	Mass [g] (mean)
Foamglass 2.1 Mpa	22	176	19.3			
Foamglass 2.1 Mpa	20	160	25.5			
Foamglass 2.1 Mpa	23	184	19.3	21.5	182.5	21.1
Foamglass 4.4 Mpa	47	376	25.3			
Foamglass 4.4 Mpa	50	420	27.2			
Foamglass 4.4 MPa	47	376	27.1	49.8	403.0	28.0
AGK2010 (Lunar regolith anloague)	3	24	218			
AGK2010	3	24	267.9			
AGK2010	4	32	276.5	3.3	26.7	254.1
OU Soil Simulant (Phobos analogue)	20	160	294.9			
OU Soil Simulant	26	208	233.1			
OU Soil Simulant	29	232	243.7	23.6	188.8	251.5

Packmoon^2 concept

1. Increase of TRL level of Packmoon device and its application for Lunar missions. This includes testing sampling process impact on sample with **volatiles in vacuum** conditions and testing sampling impact on rover in **Lunar gravity** conditions
2. Scale-up of the Packmoon to provide industry oriented service: e.g. to excavate and provide 500 kg of Lunar regolith



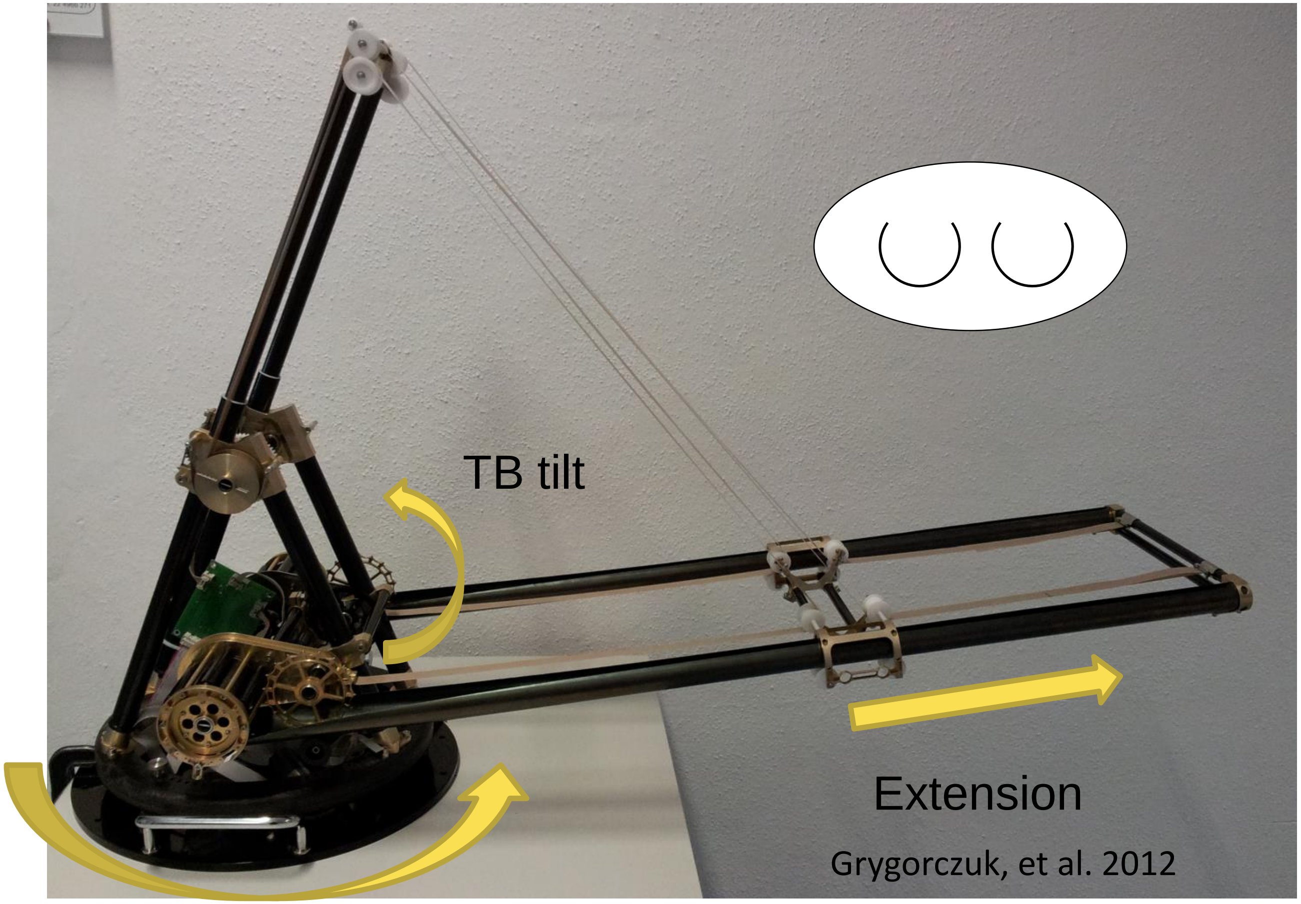
Possible system topology

Target parameters:

Mass reg.	~500kg
Time	~20 min
Power	~ 25W

Drill string and tubular booms

Horizontal movement



Joint rotation

Values:
Extension: **3.2 m**
TB tilt: **+/- 30º**
Joint rotation: **+/- 60º**

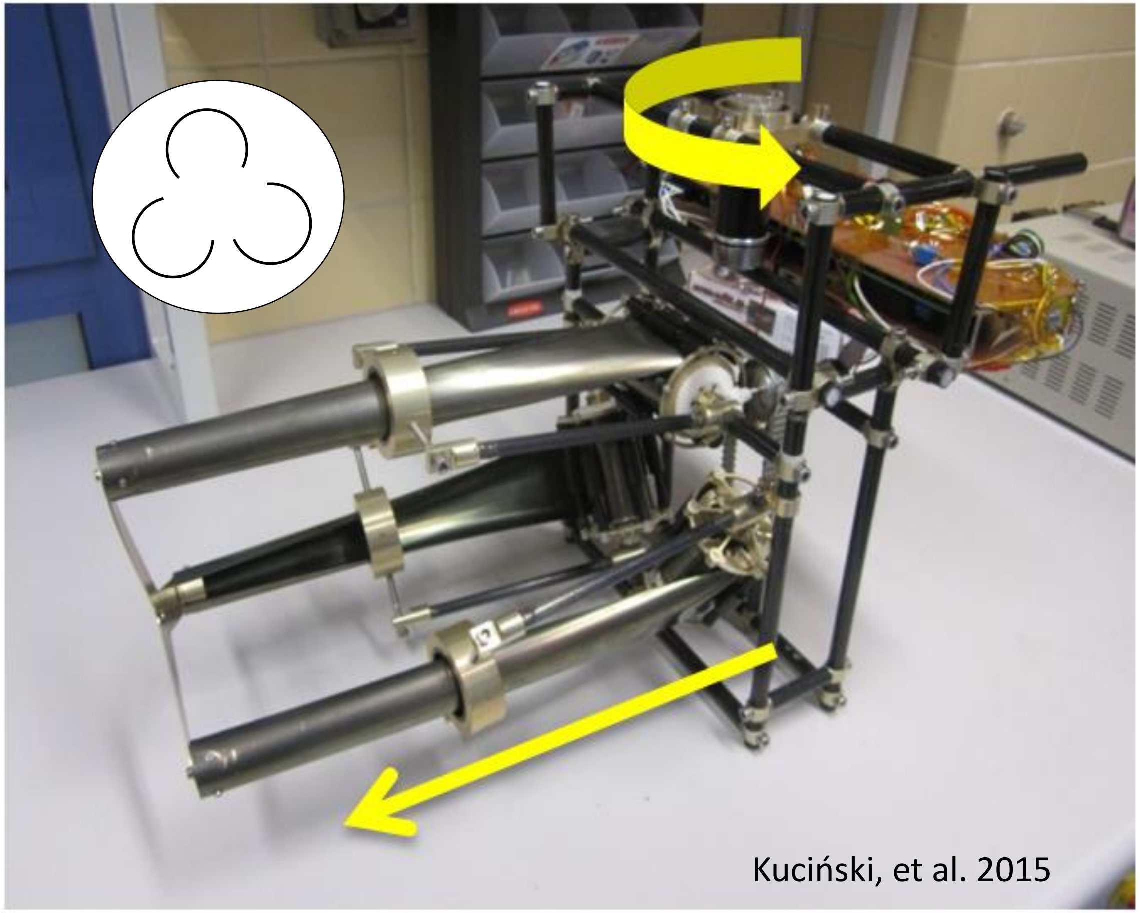
Eigenfrequency:
~3 Hz
with **2.2m** TB extension and **1.3kg** load on the TB end

Parameters:
Mass: **2.3kg**
Load: **2kg on 2m in Earth gravity**

Vertical movement

Properties
- no force transfer along extension axis
- possibility to reorient end effector

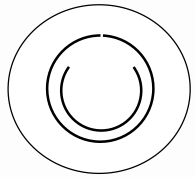
Dimensions	0.3m x 0.4m (min. length) x 0.34m
Max. length	2 m
Mass	3.4 kg
Max. power consumption	~40W



Kuciński, et al. 2015

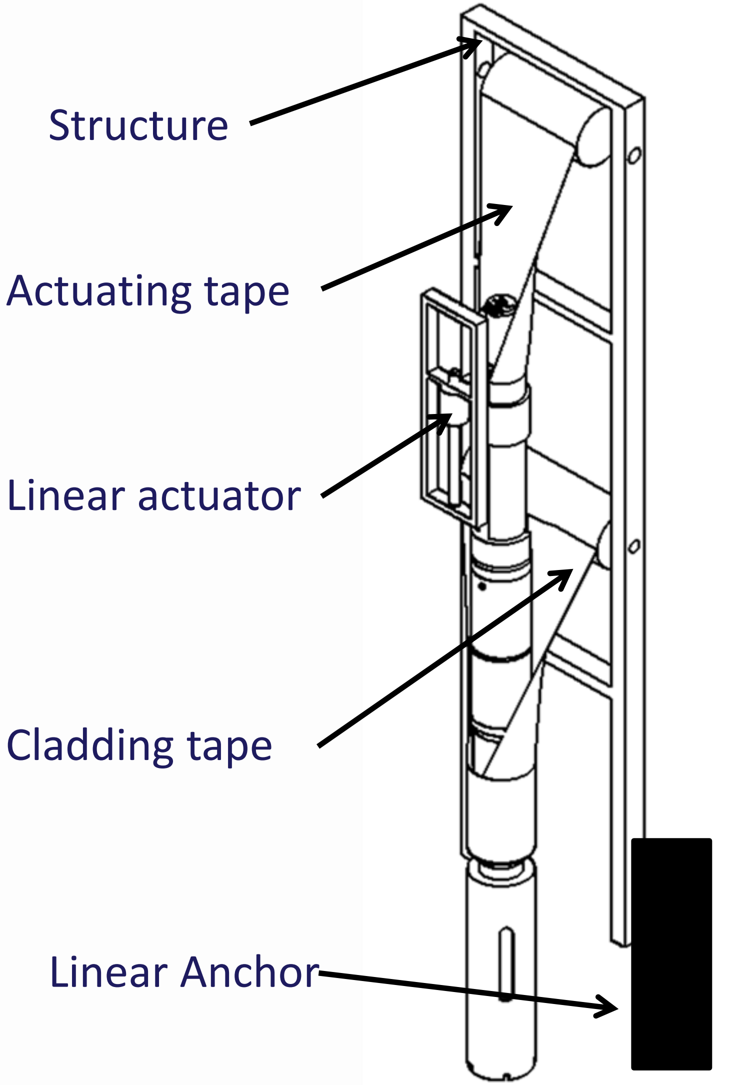
Vertical movement

1. Cross section

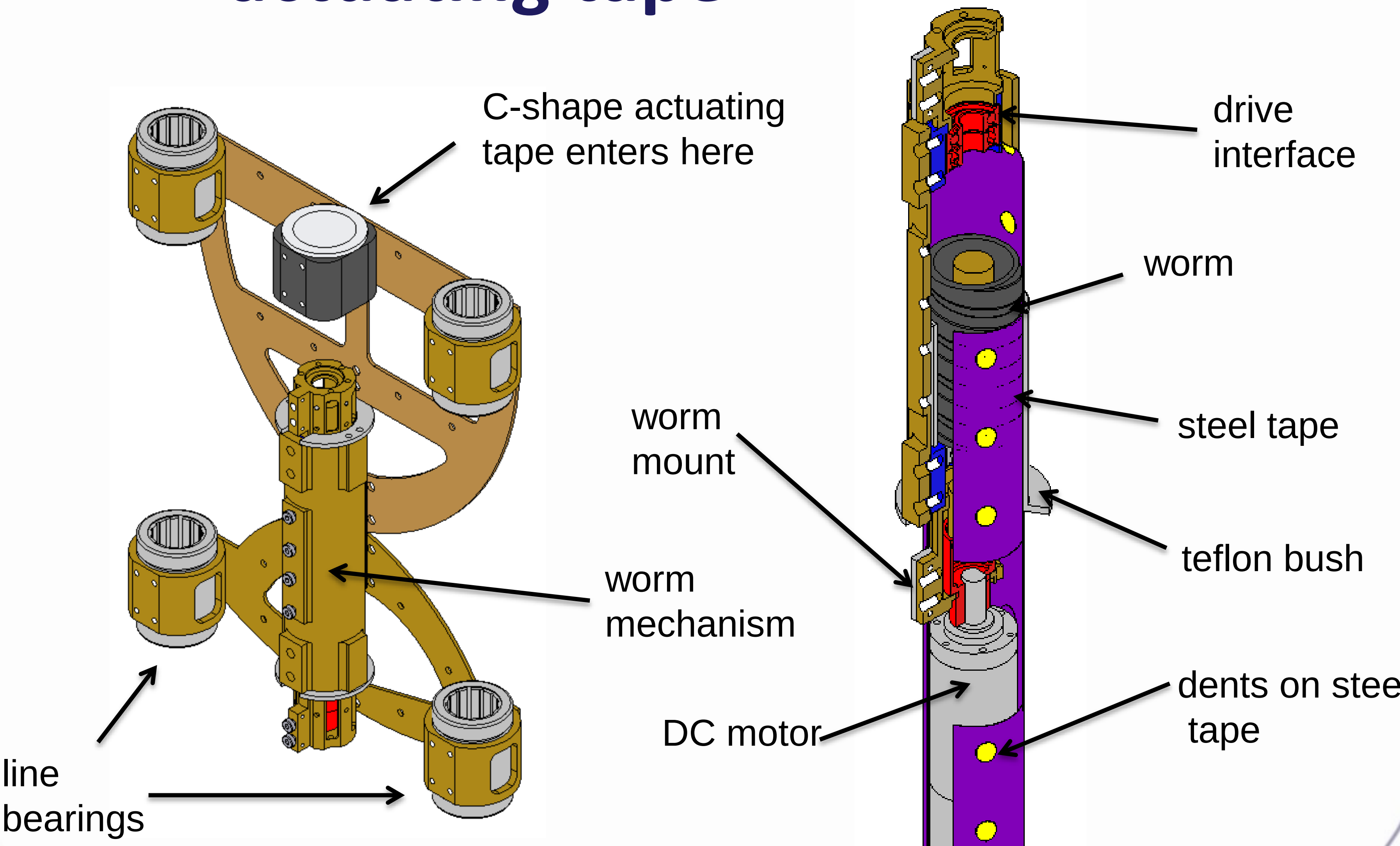


2. Drill string made of 2 steel C-shape tubular tape: one (ϕ=25mm, α=330deg) to actuate the drill head and one (ϕ=36mm, α=400deg) to secure the borehole

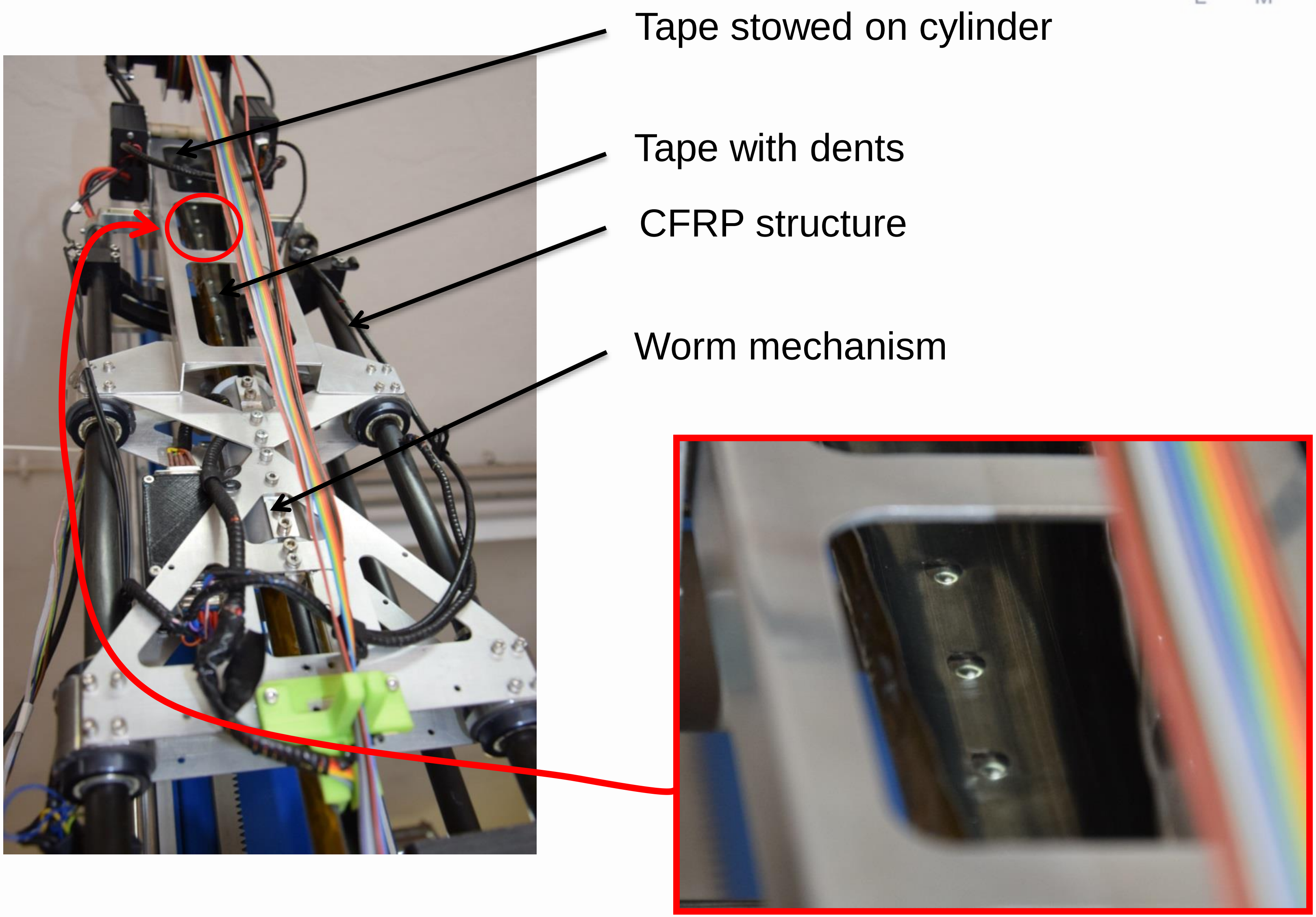
3. Linear actuator to transfer 500N force



Linear actuator and actuating tape



Linear Actuator Prototype



Conclusions

1. The concept of prospecting and excavation of non easily accessible places on Moon was presented
2. The PACKMOON sampling device was developed:

- Relatively large sample can be collected (100 – 300 cm^3) which is structurally and thermally not impacted by sampling process
- The device is small and compact (<3kg, 15x15x18cm size)
- Low power consumption (<10W) with high energy impact
- Sample is secured to be not cross contaminated

and the concept of scale-up version was presented.

3. The tubular boom technology was analyzed as a potential solution for drill head and excavation head transportation

PACKMOON on Moon … or other low gravity body