Can we successfully use elastomers on Mars?

Rafal Anyszka[1-3], Norbert Nizel[3], Dariusz Bielinski[3], Piotr Szajerski[4], Li Jia[2], Anke Blume[1]

[1] University of Twente, Faculty of Engineering Technology, Department of Mechanics of Solids, Surfaces & Systems (MS3), Chair of Elastomer Technology & Engineering, Enschede, The Netherlands

[2] The University of Akron, The School of Polymer Science and Polymer Engineering, Akron, Ohio, United States

[3] Lodz University of Technology, Faculty of Chemistry, Institute of Polymer and Dye Technology, Poland

[4] Lodz University of Technology, Faculty of Chemistry, Institute of Applied Radiation Chemistry, Poland

RED 4 MARS

I·M3 Institute of Materials, Minerals & Mining

Lodz University of Technology

UNIVERSITY OF TWENTE.

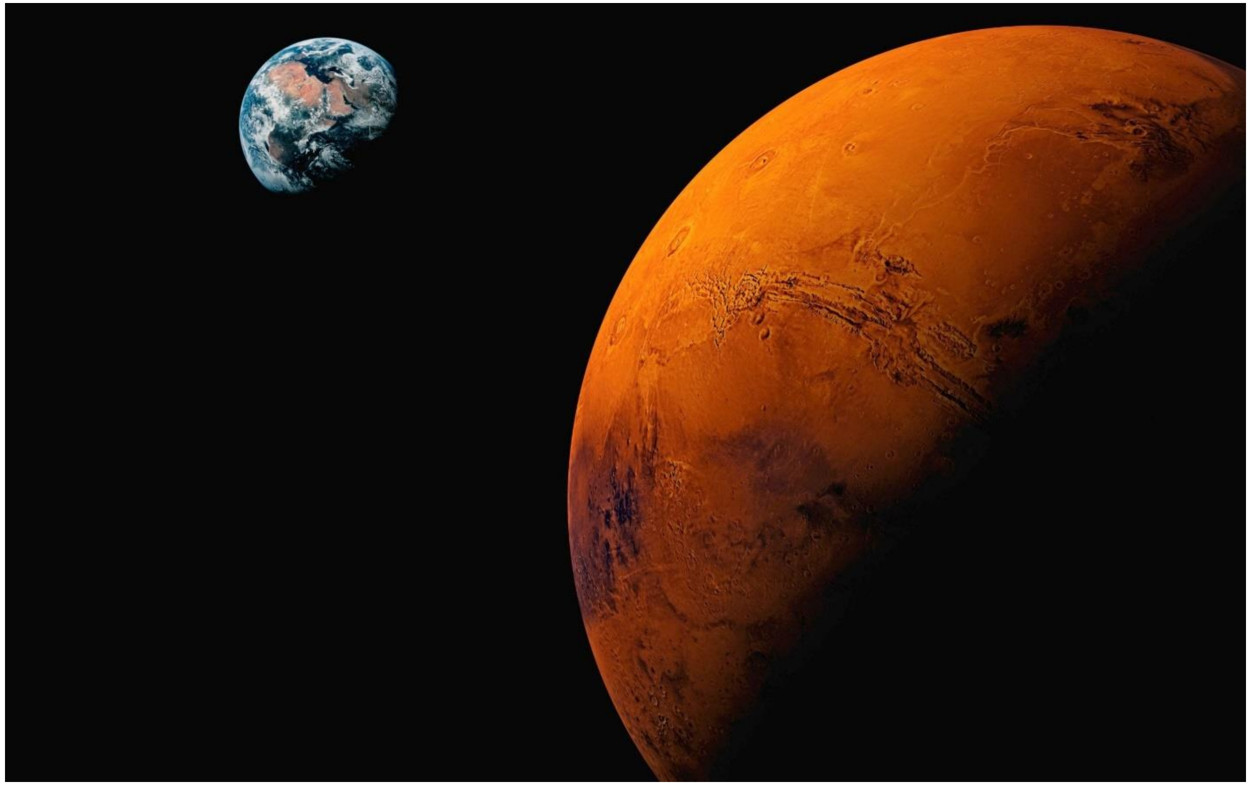
THE UNIVERSITY OF AKRON · FIAT LUX · 1870

What is commonly known about the Mars?

- Let‘s google it and see what we can learn from the internet:

What is commonly known about the Mars?

- Let‘s google it and see what we can learn from the internet:



- fourth planet from the Sun
- named for the Roman god of war
- Known also as “Red planet”
- minimum distance from Earth to Mars: about 54.6 million kilometers

https://www.cnbc.com/2018/03/25/one-strange-rock-collaborators-explain-what-life-on-earth-means-for-humans-looking-to-mars.html

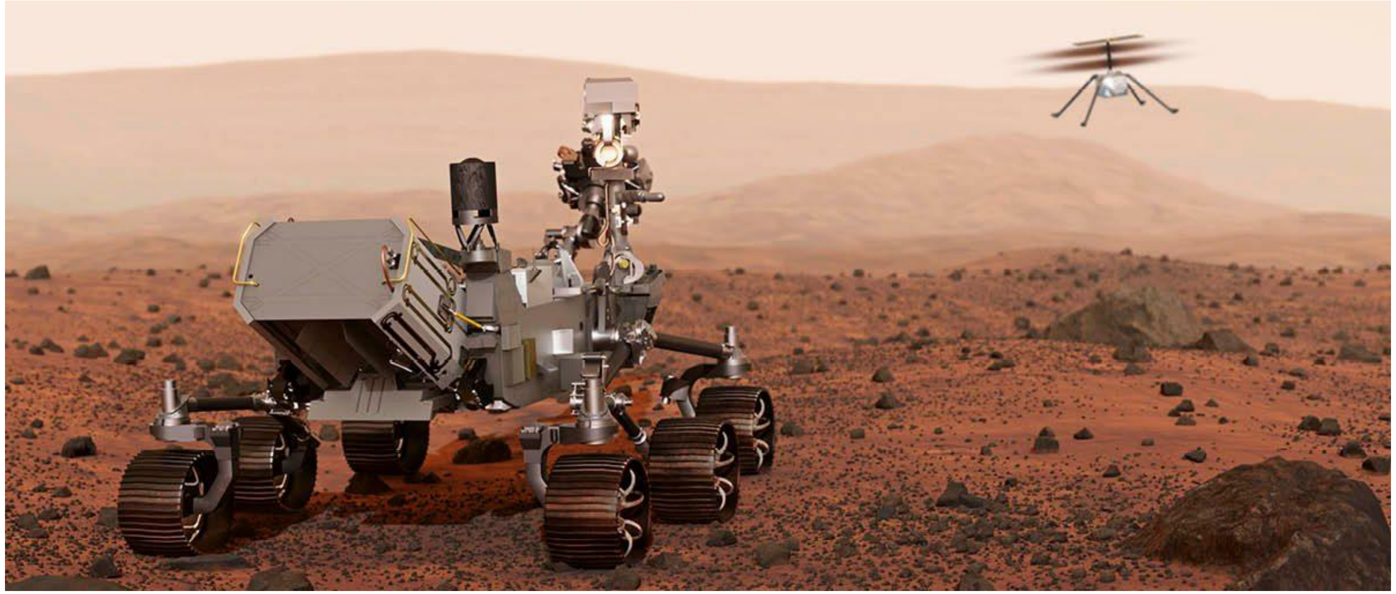
Why?

Why do we need rubber on Mars?

https://www.planet-wissen.de/natur/weltall/mars/pwiewissensfrage400.html; https://www.space.com/47-mars-the-red-planet-fourth-planet-from-the-sun.html

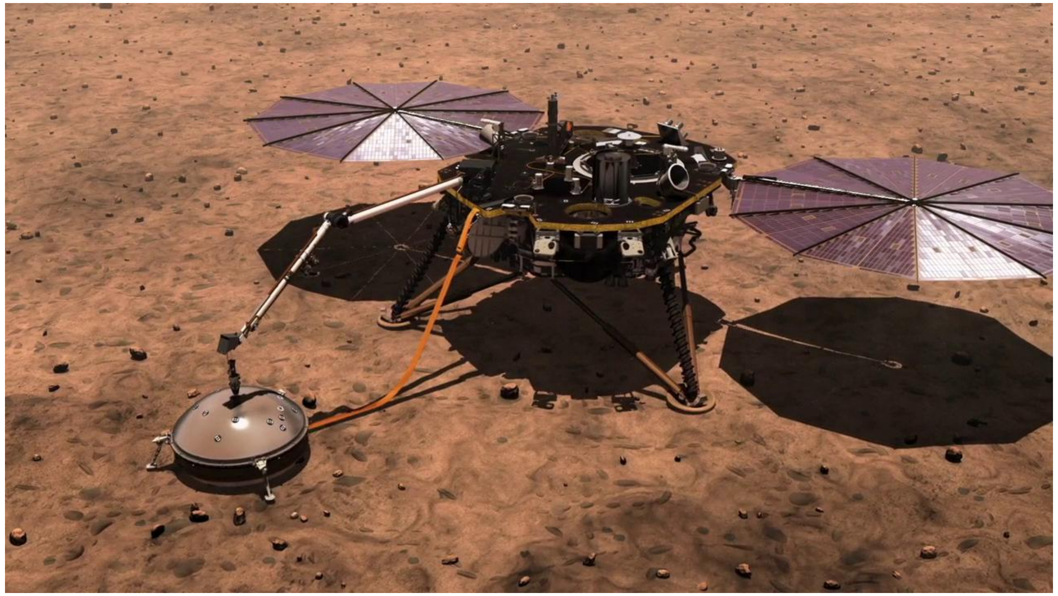
Current missions - examples

Rover - *Perseverance* Helicopter - *Ingenuity*



https://www.sciencefocus.com/news/perseverance-a-year-on-mars/

Lander - *InSight*



https://mars.nasa.gov/insight/

Not rubber but metal seals are used in machines operating on Mars

https://www.eaton.com/us/en-us/catalog/seals/c-seals.html

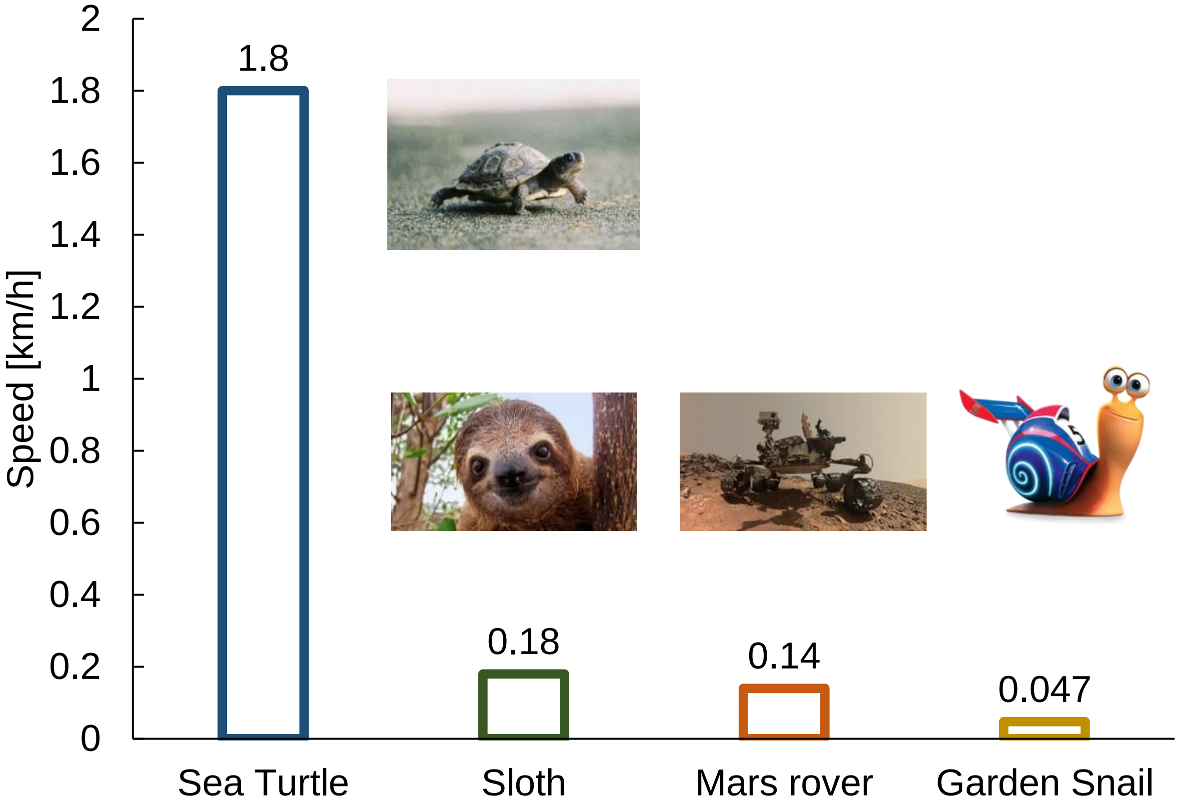
RED 4 MARS

Current missions - examples

Aluminum wheels

https://www.reddit.com/r/space/comments/2dj1xb/comparative_wheel_sizes_of_mars_rovers/
https://i.stack.imgur.com/HejZ8.jpg

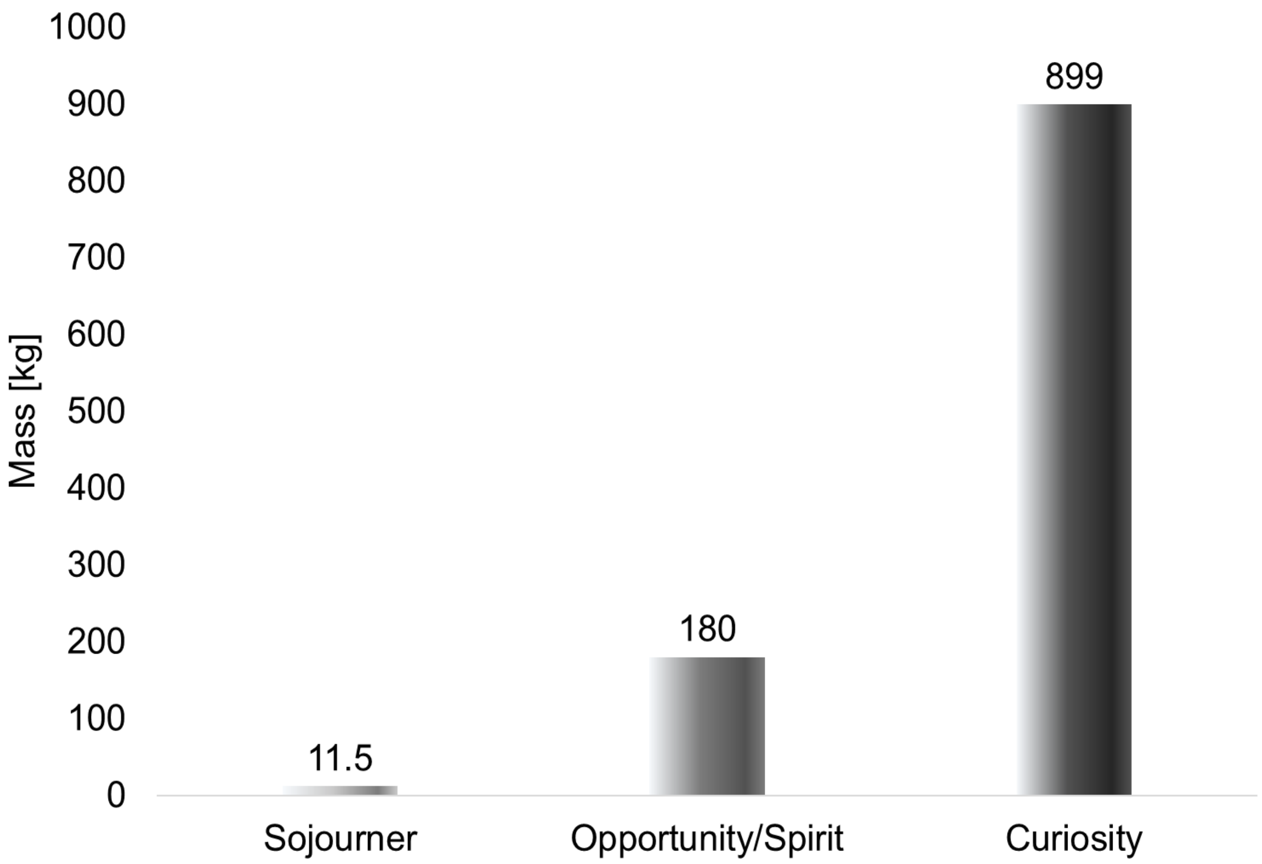
Speed comparison



https://saxstation.com/playing-saxophone-by-earmemory.htm
https://polki.pl/magazyn/zjawisko,7-faktow-o-leniwcach-niektore-szokujace,10419763,artykul.html
https://mars.nasa.gov/msl/home/
https://turbo.fandom.com/wiki/Turbo_(character)

Current missions - examples

Mars rovers' mass



Curiosity's wheel damage

https://www.spaceflightinsider.com/missions/solar-system/wheel-treads-break-curiosity-rover/

Current missions - examples

Self-driving rovers

ESA's program started in 2019

"…they'll be moving hundreds of meters per day."

- Currently, no rubber is used on Mars
- Increasing the speed of Mars rovers could result in accelerated wheel and equipment damage caused by vibrations
- Tailored rubber for Mars could be the solution

https://earthsky.org/space/mars-rovers-self-driving-technology-tested-by-uk

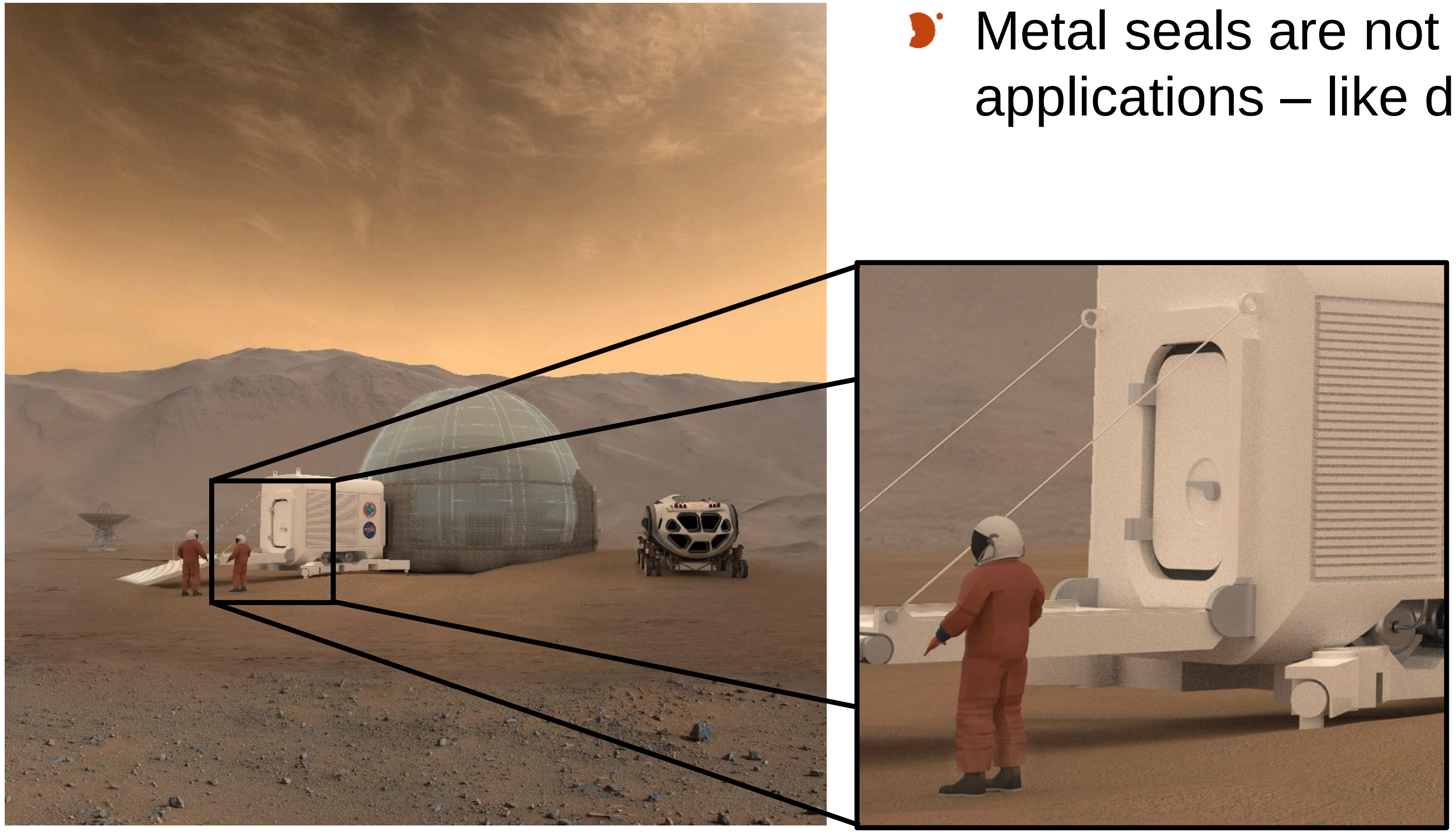
How about future Mars missions?

In Israel, six analog astronauts are living and working in a small structure to simulate life on Mars.

Mars Simulation in Israel Is Prep for a Future Mission to Red Planet (businessinsider.com)

Future missions

Mars habitat

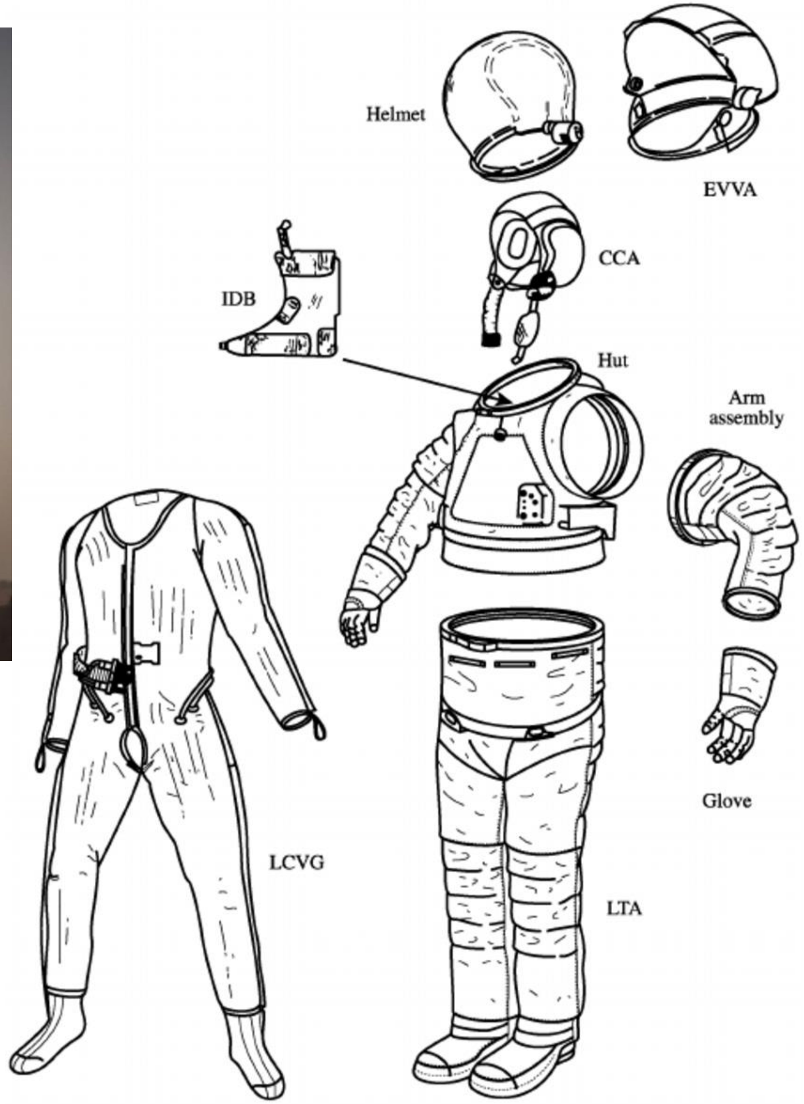


https://upload.wikimedia.org/wikipedia/commons/5/5f/Mars_Ice_Home_concept.jpg

- Metal seals are not preferable for dynamic applications – like door sealing
- Rubber-based composites exhibit superior dynamic sealing performance

Mars spacesuit

https://www.theverge.com/2017/8/19/16104004/science-fiction-space-suit-worst-best-the-martian-alien-sunshine-gravity



https://saemobilus.sae.org/content/2001-01-2368/

- Spacesuit consists of several elements that need to be assembled and disassembled frequently
- Efficient sealing of the connection of the elements is essential
- Rubber-based seals guarantee the best performance

Future missions

Mars rover

https://en.wikipedia.org/wiki/The_Martian_(film)

Speed = 0.14 km/h
Weight = 1 ton

https://mars.nasa.gov/mars2020/spacecraft/instruments/

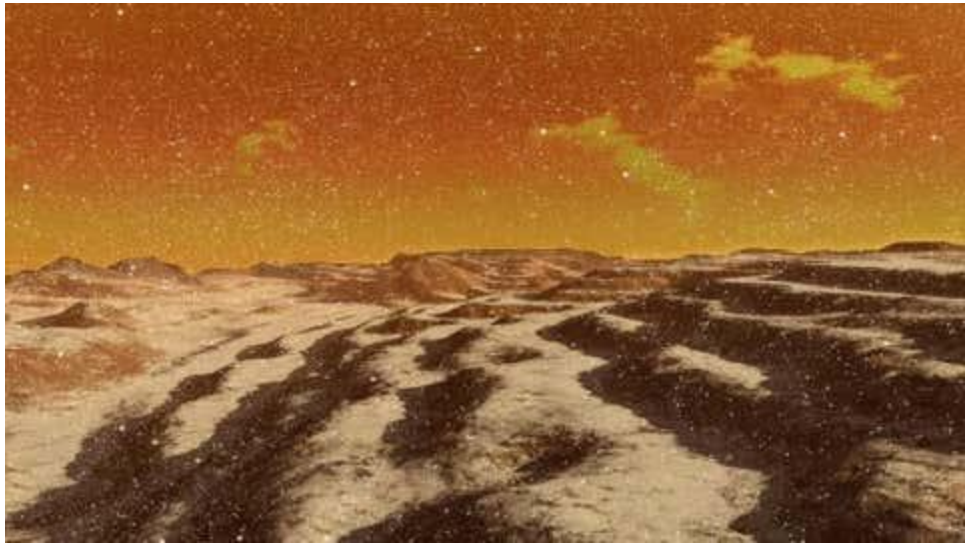
https://the-martian.fandom.com/wiki/Rover_2

Speed >50 km/h
Weight > 5 tons

- Rubber tires/tracks and dampers are needed

Which weather conditions do we have to face on Mars?

Several times a year a dust storm of titanic size blooms on Mars



Snowy morning near the south pole of Mars: snowflakes = frozen CO_2 ; T = –129 °C

https://weather.com/science/news/check-weather-mars-where-nasas-maven-headed-20131119

Comparison of Earth and Mars environments

	Earth	Mars
Temperature range	(-88 °C) – 58 °C	(-140 °C) – 30 °C
Pressure	101.3 kPa	0.6 kPa
Radiation	Low – 0.003 Gy/a	High – 0.1-0.2 Gy/a; additionally occasional solar proton events; UV radiation
Atmosphere	21 % oxygen; 78 % nitrogen; 1 % other	96 % carbon dioxide; <2 % argon; <2% nitrogen; <1% other

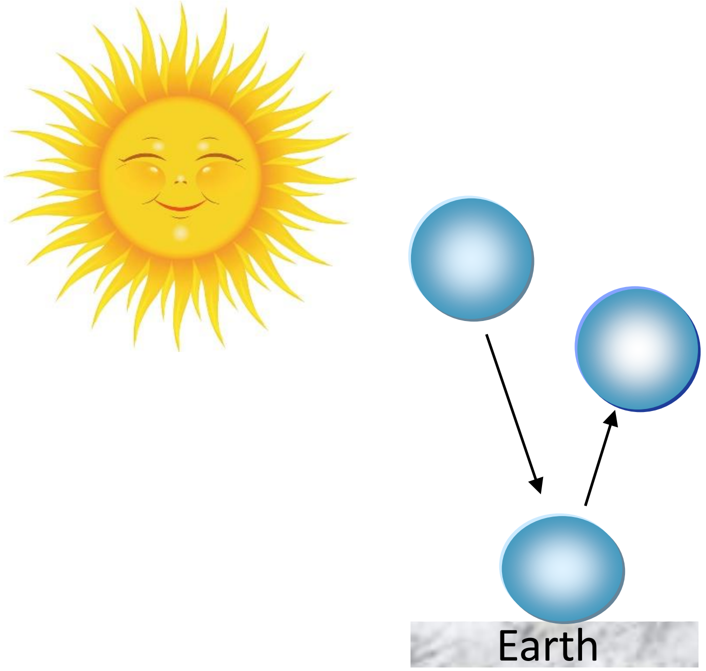
https://visibleearth.nasa.gov/images/54388/earth-the-blue-marble
https://solarsystem.nasa.gov/planets/mars/in-depth/
https://mars.nasa.gov/all-about-mars/facts/

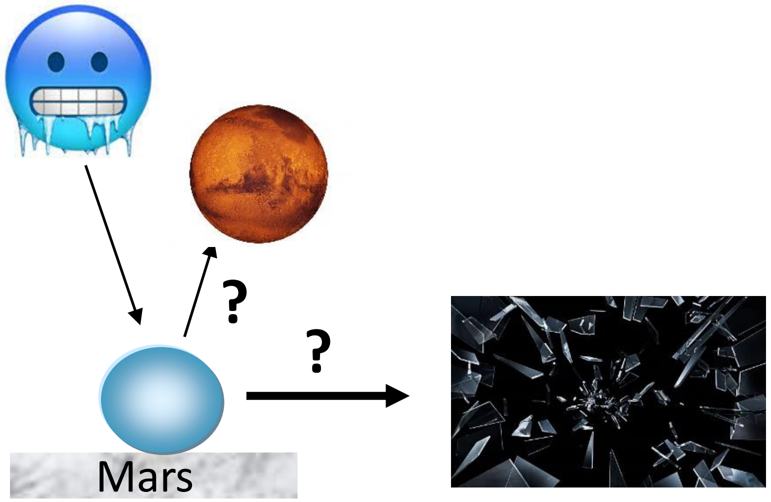
Comparison of Earth and Mars environments

	Earth	Mars
Temperature range	(-88 °C) – 58 °C	(-140 °C) – 30 °C
Pressure	101.3 kPa	0.6 kPa
Radiation	Low – 0.003 Gy/a	High – 0.1-0.2 Gy/a; additionally occasional solar proton events; UV radiation
Atmosphere	21 % oxygen; 78 % nitrogen; 1 % other	

Very small amount of oxygen
=
less oxidation aging ✓

How to design rubber for Mars?

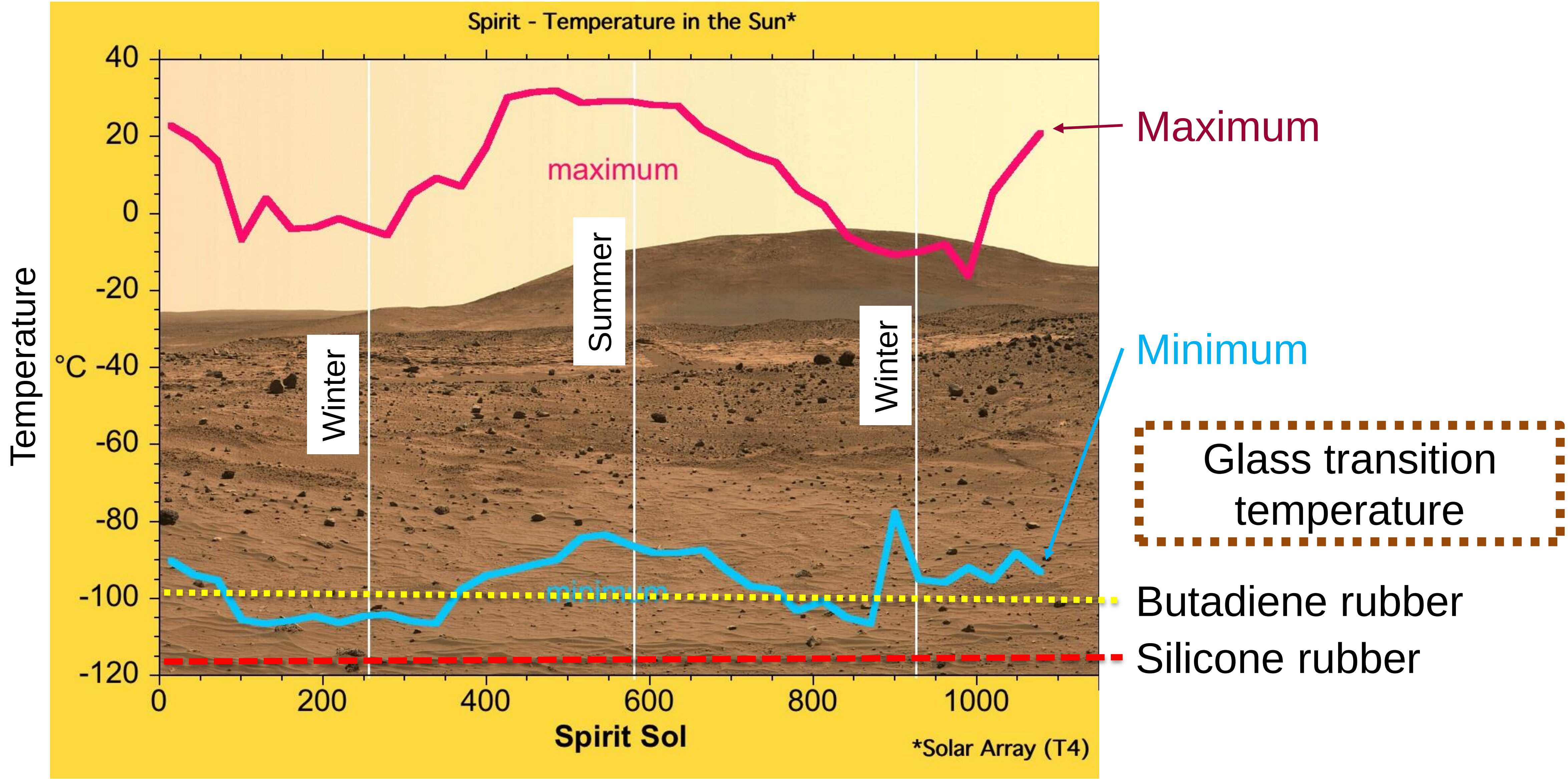




How to remain elastic at such cold conditions?

https://www.vectorstock.com/royalty-free-vector/sunshine-vector-493377; https://de.freepik.com/fotos-premium/planet-mars-isoliert-auf-weissem-hintergrund_16986775.htm

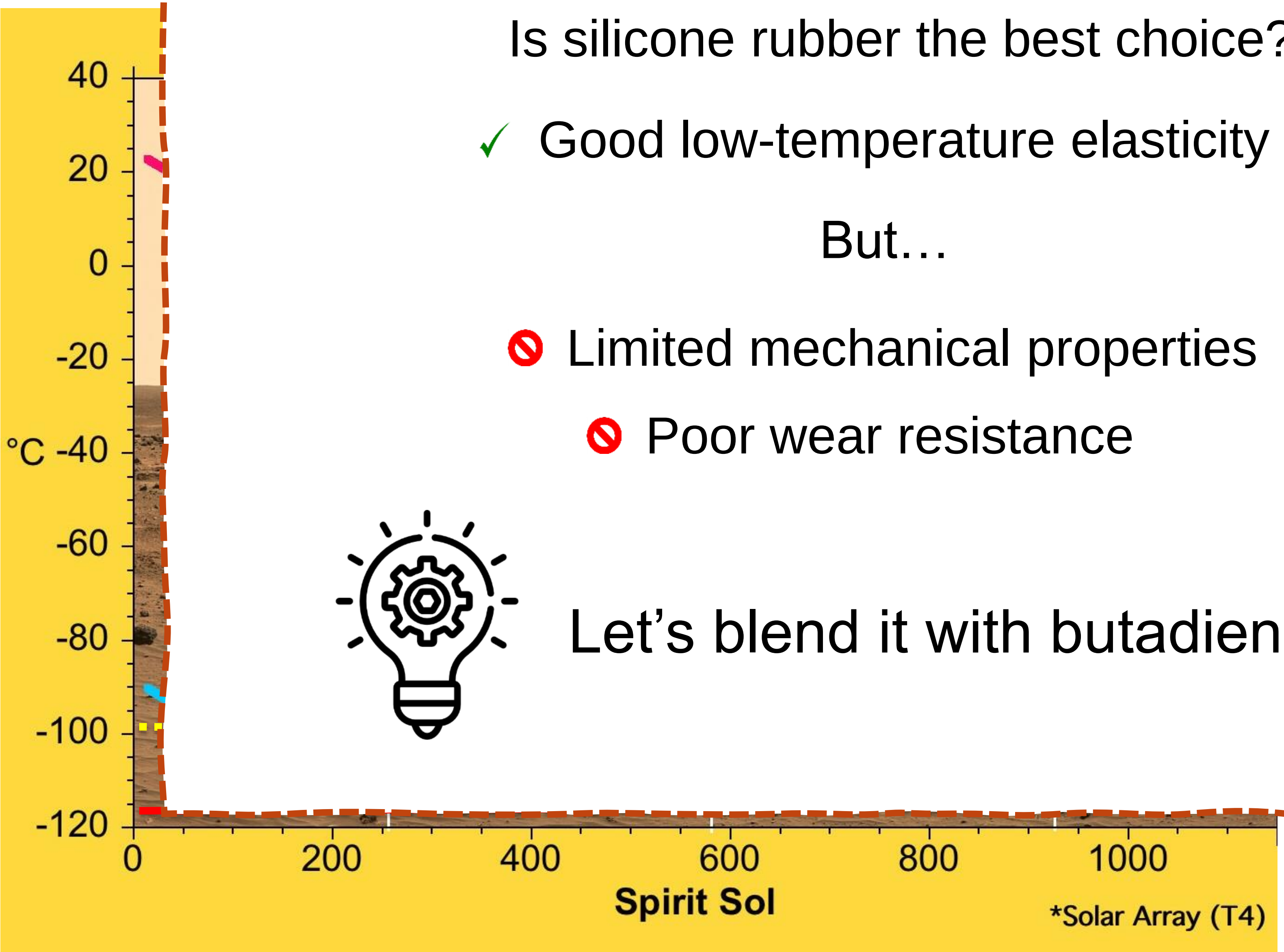
Can the rubber flexibility be preserved on Mars?



https://mars.nasa.gov/mer/spotlight/20070612.html

RED 4 MARS

Can the rubber flexibility be preserved on Mars?



Is silicone rubber the best choice?

✓ Good low-temperature elasticity

But…

- Limited mechanical properties
- Poor wear resistance

Let's blend it with butadiene rubber!

nsition
ature

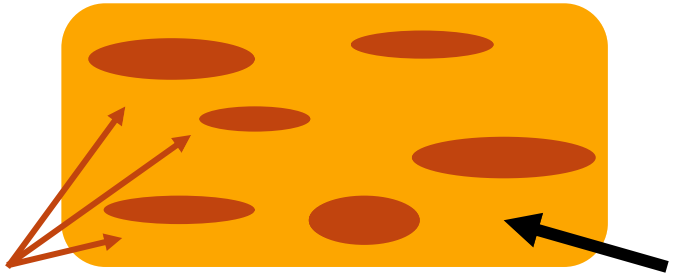
bber
er

https://mars.nasa.gov/mer/spotlight/20070612.html

Idea – blending of silicone (VMQ) & butadiene rubber (BR)

Blend of Silicone (VMQ) and Butadiene Rubber (BR)

*No risk of fast **aging** of BR due the **absence of oxygen***



Dispersed phase

Silicone rubber:

- ✓ Very good low temperature elasticity
- ✓ Good UV resistance
- ✗ Low abrasion resistance
- ✗ Low mechanical properties

Continuous phase

Butadiene rubber:

- ✓ Good low-temperature elasticity
- ✓ High abrasion resistance
- ✓ High mechanical properties
- ✗ Low UV resistance

How to homogenize BR with VMQ?

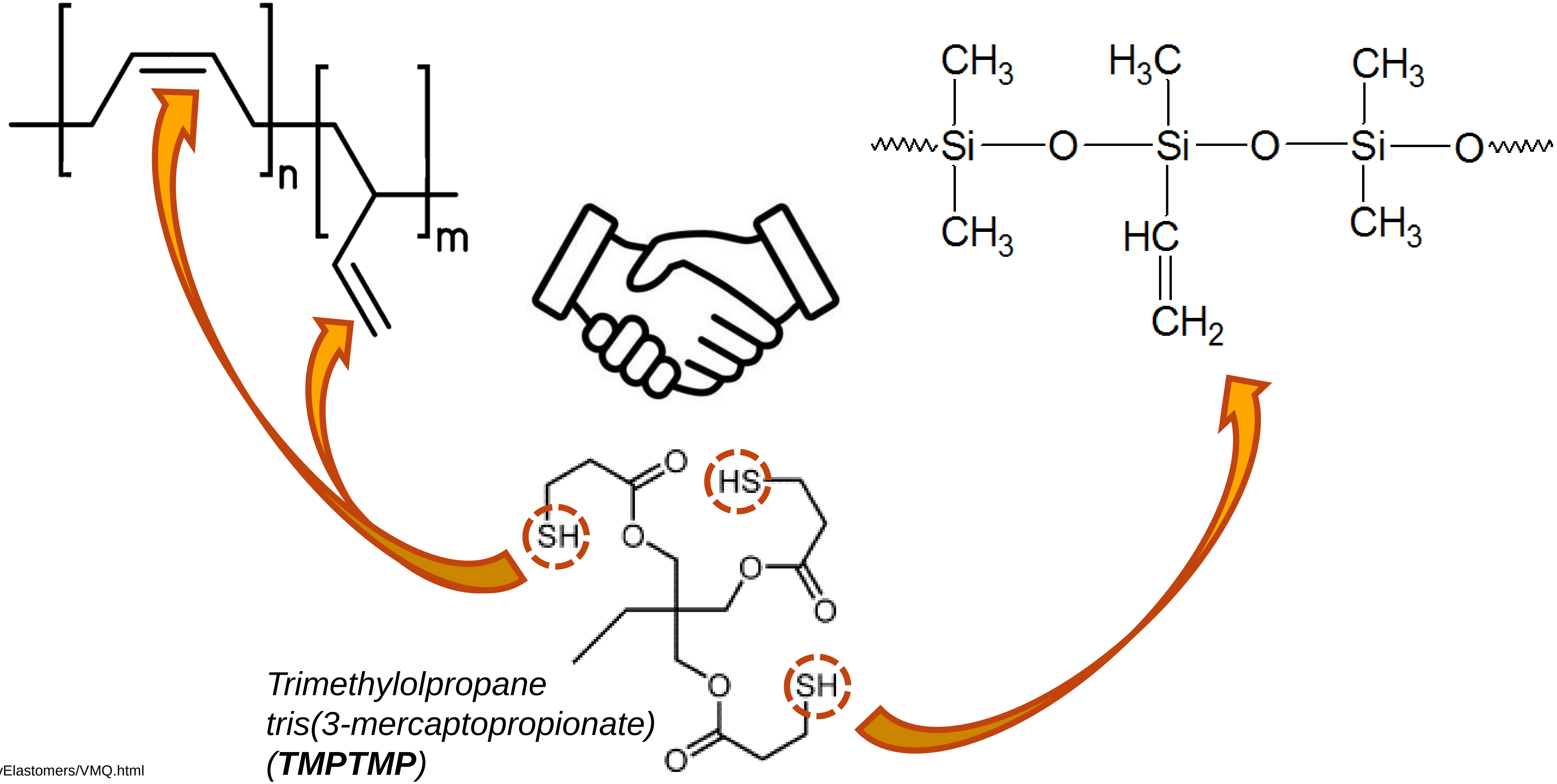
Chemical compatibility guide

	VMQ (silicone)
butadiene	**4 = do not use!**

N1021A_Novotema_Elastomer_Chemical_Compatibility_Brochure_EN.pdf

Idea – chemical coupling of VMQ & BR

Butadiene rubber **Methyl vinyl silicone rubber**



*Trimethylolpropane tris(3-mercaptopropionate) (**TMPTMP**)*

http://polymerdatabase.com/vElastomers/VMQ.html
https://en.wikipedia.org/wiki/Polybutadiene

Idea – chemical coupling of VMQ & BR

Formulation

Ingredient [phr]	REF	Coupl	BR green	VMQ green
Butadiene rubber	80	80	100	-
Silicone rubber	20	20	-	100
ZnO	5	5	-	
Stearic acid	3	3	-	
Sulfur	1.2	1.2	-	
CBS	1.6	1.6	-	
Trimethylolpropane tris(3-mercaptopropionate)	-	4	-	

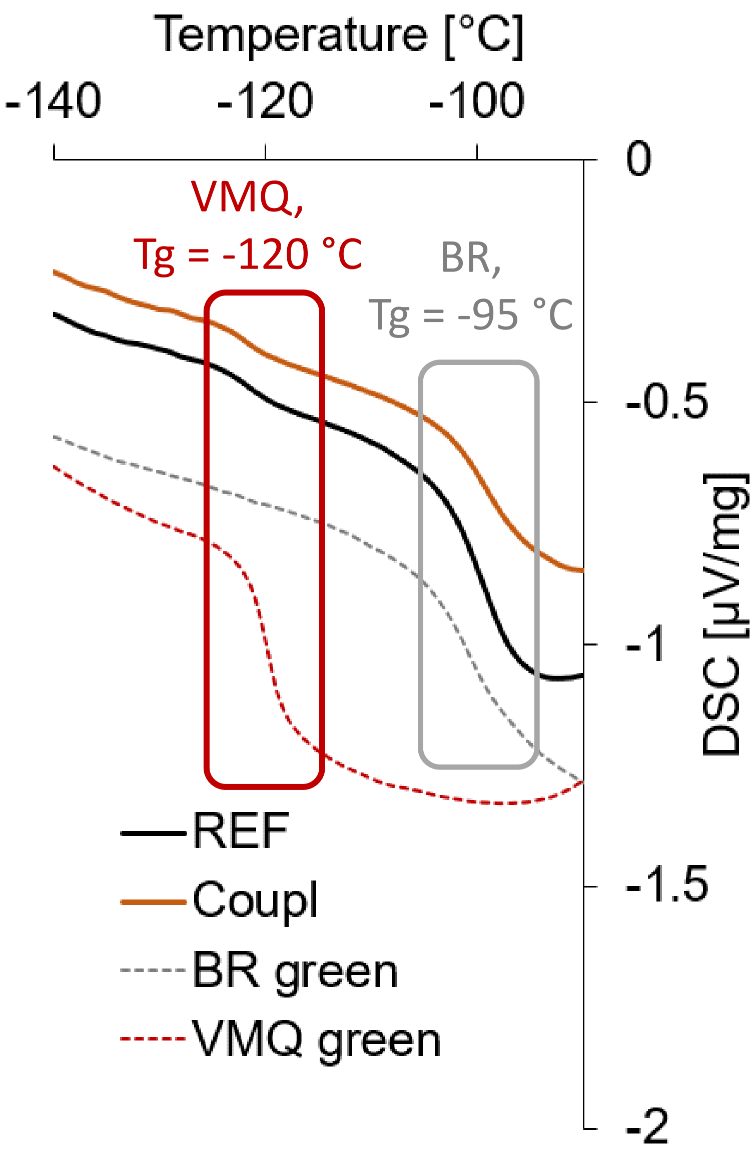
Idea – chemical coupling of VMQ & BR

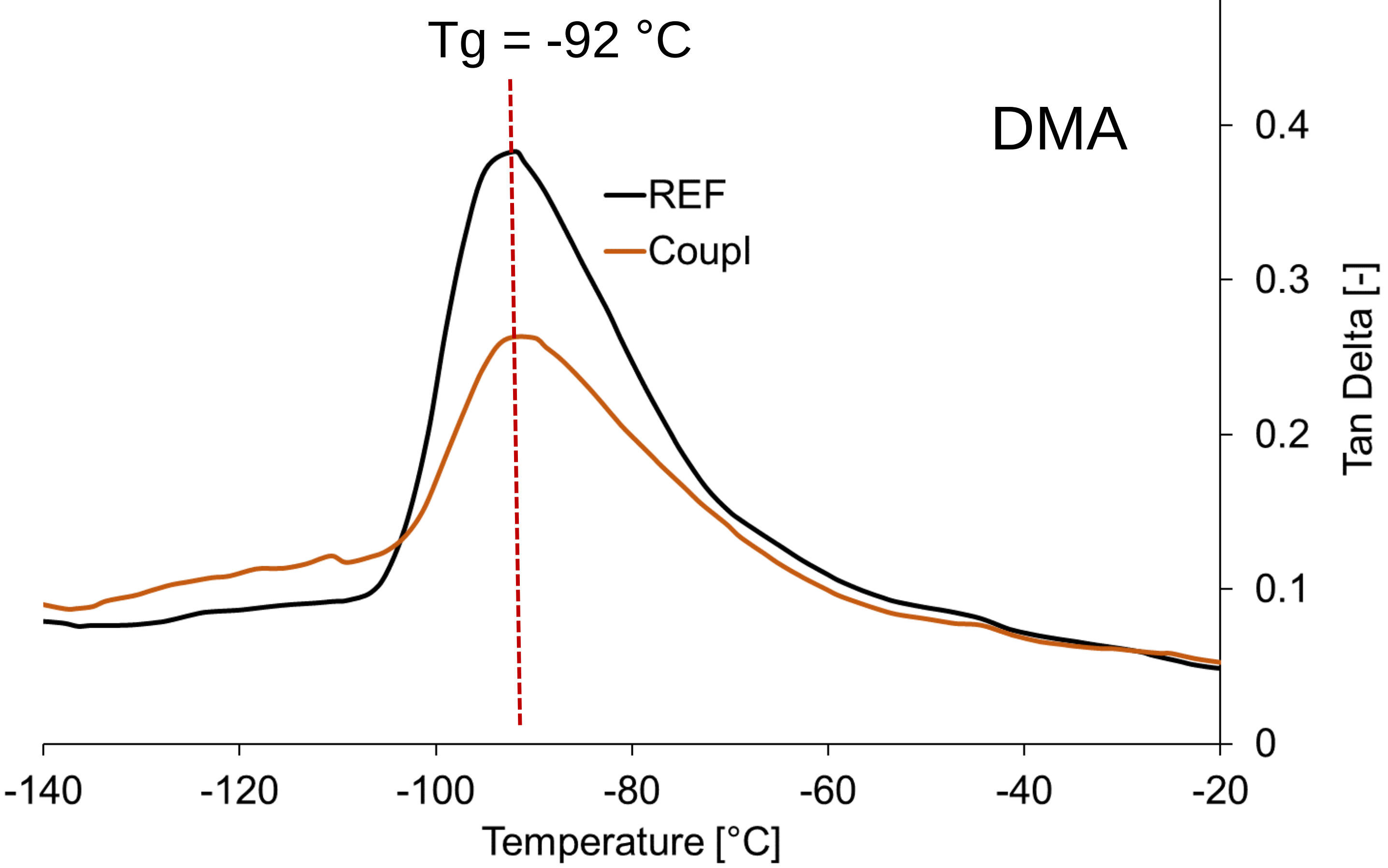
Mixing procedure

Mixing conditions Laboratory mixer 50 cm^3	
Temperature	70 °C
Temp. rise	70 °C → 90 °C
Time	4 min + 1 min with curatives
Rotor speed	20 rpm (incorporation), 60 rpm (homogenization)

Idea – chemical coupling of VMQ & BR

DSC and DMA investigation of the glass transition temperature of the blends





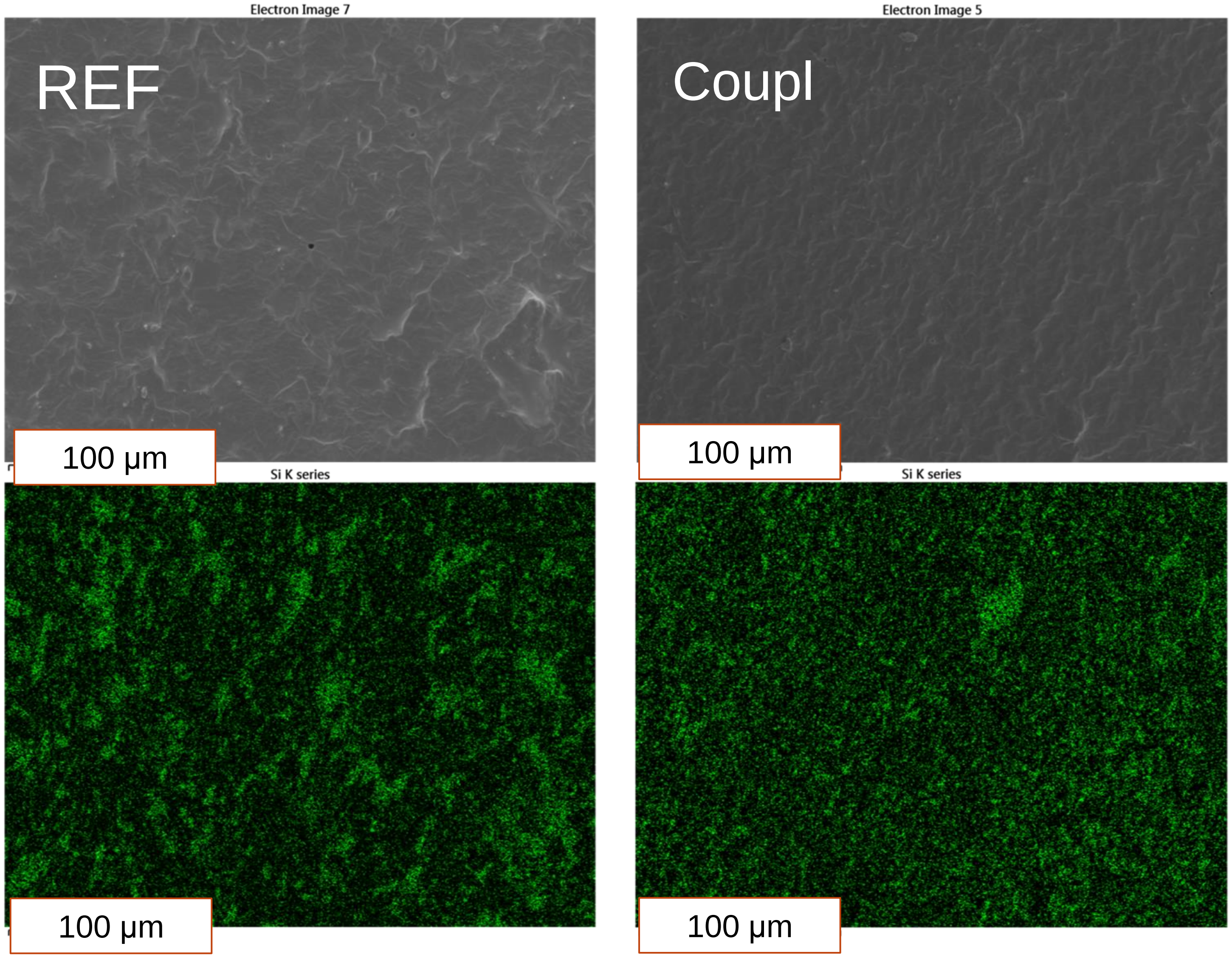
Idea – chemical coupling of VMQ & BR

VMQ + BR | *VMQ + BR + TMPTMP*

SEM

EDX

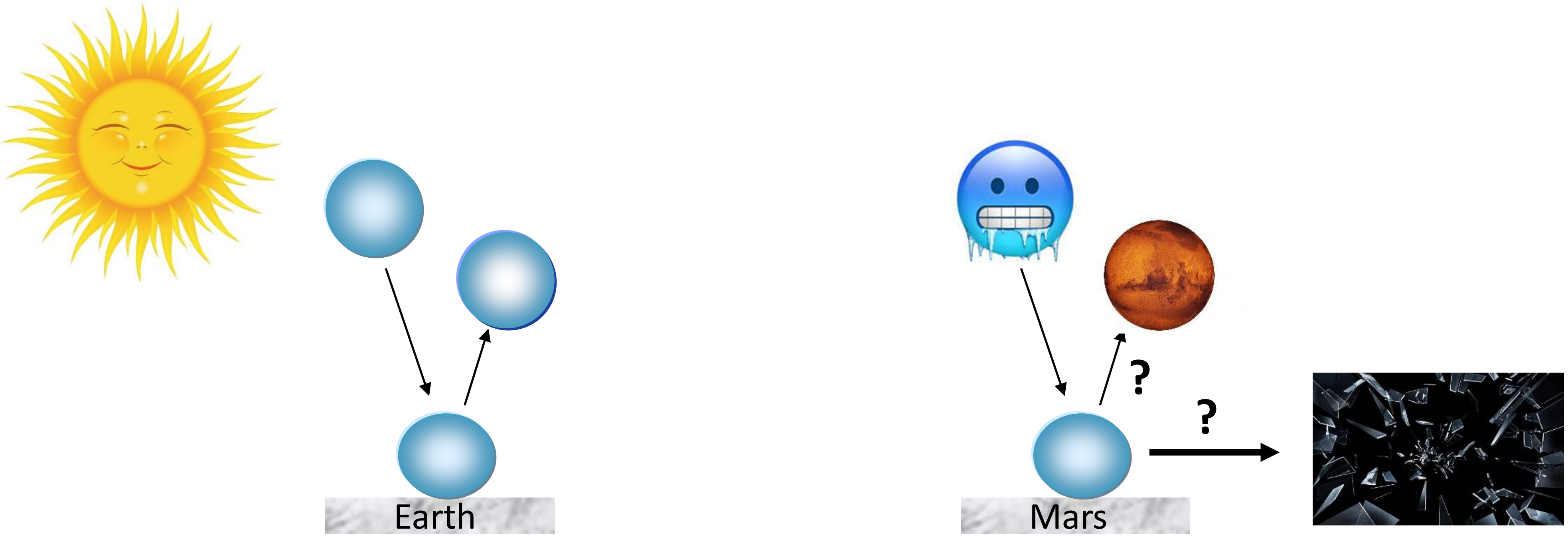
Si mapping



Micromorphology investigation

- Significant improvement in the silicone rubber dispersion

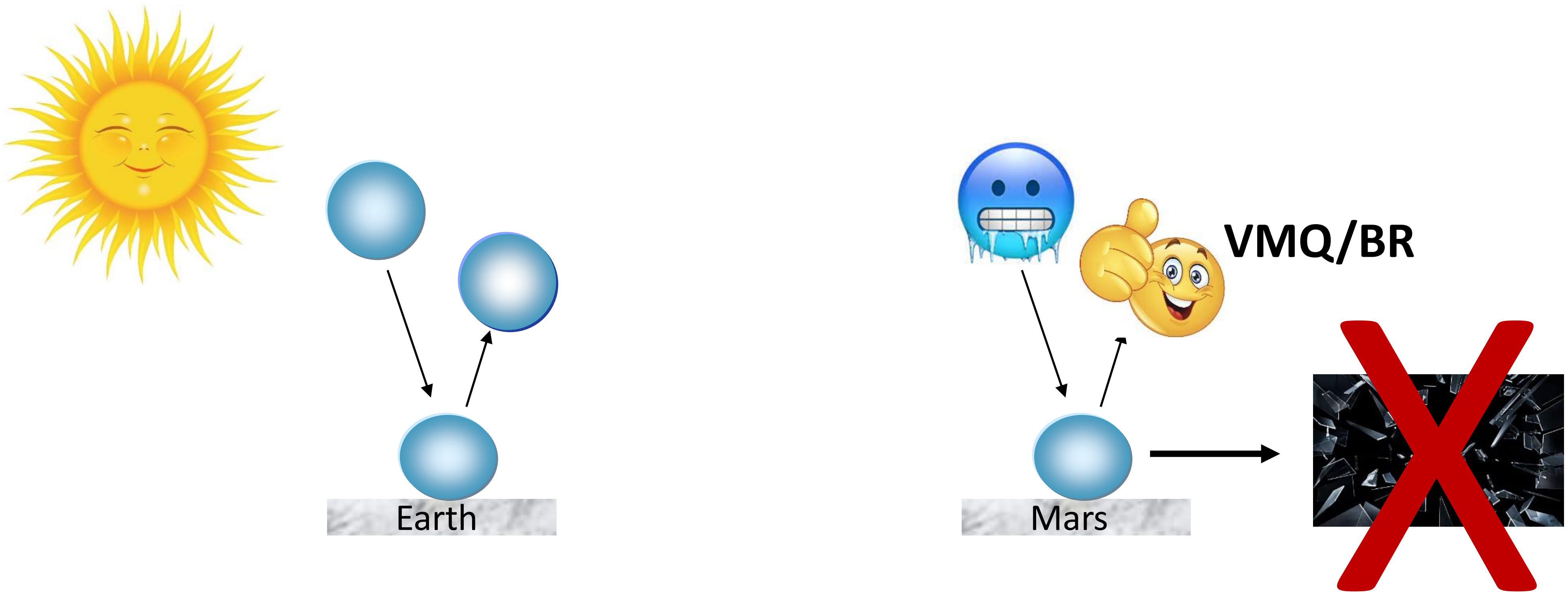
How to design rubber for Mars?



How to remain elastic at such cold conditions?

https://www.vectorstock.com/royalty-free-vector/sunshine-vector-493377; https://de.freepik.com/fotos-premium/planet-mars-isoliert-auf-weissem-hintergrund_16986775.htm

How to design rubber for Mars?



https://www.vectorstock.com/royalty-free-vector/sunshine-vector-493377; https://de.freepik.com/fotos-premium/planet-mars-isoliert-auf-weissem-hintergrund_16986775.htm

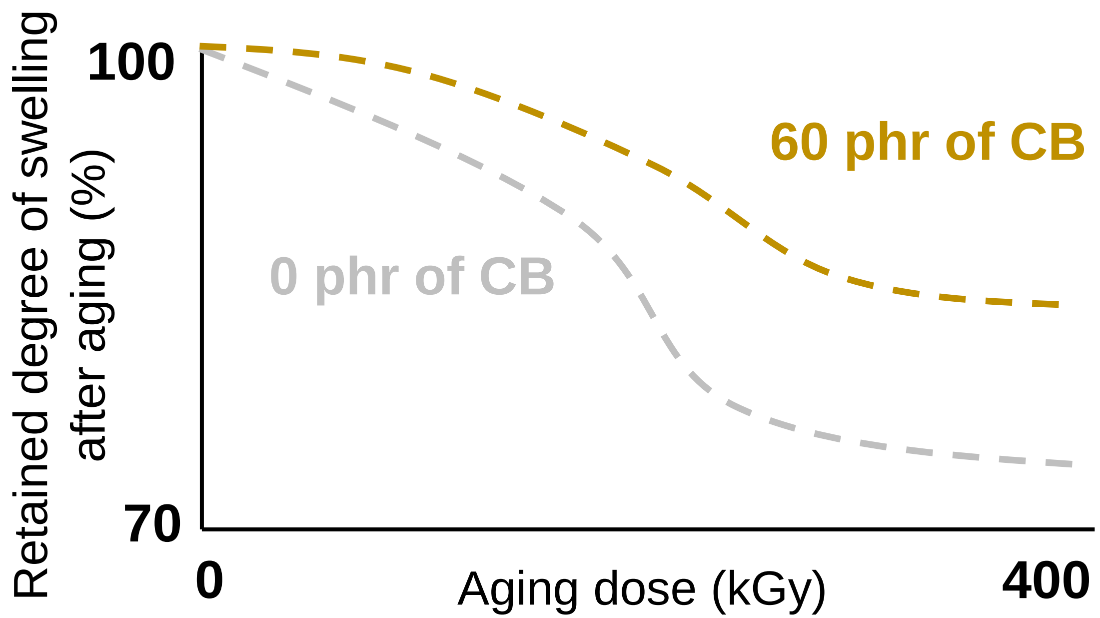
What about radiation aging?

	Earth	Mars
Temperature range	(-88 °C) – 58 °C	(-140 °C) – 30 °C
Pressure	101.3 kPa	0.6 kPa
Radiation	Low – 0.003 Gy/a	High – 0.1-0.2 Gy/a; additionally occasional solar proton events; UV radiation
Atmosphere	21 % oxygen; 78 % nitrogen; 1 % other	96 % carbon dioxide; <2 % argon; <2% nitrogen; <1% other

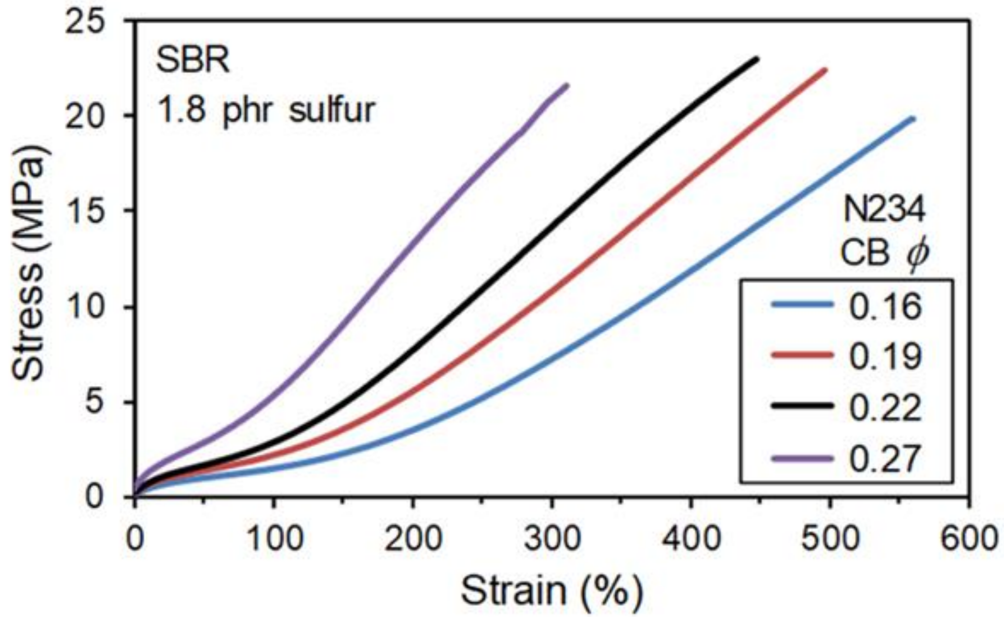
Idea – one filler for many problems

Carbon Black addition - Expectations

- Addition of carbon black increases the radiation[1] and UV[2] resistance



- Addition of carbon black increases the mechanical properties of rubber



✓ Carbon Black: ***N330***, specific surface area = 78 m^2/g

[1] Markovic, G., et al. Influence of carbon black on reinforcement and gamma-radiation resistance of EPDM/CSM CR/CSM rubber blends. KGK. Kautschuk, Gummi, Kunststoffe 62.6 (2009): 299-305.

[2] Spahr, M.E., Rothon, R. (2016). Carbon Black as a Polymer Filler. In: Palsule, S. (eds) Polymers and Polymeric Composites: A Reference Series. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-37179-0_36-2

Robertson, C. G., & Hardman, N. J. (2021). Nature of carbon black reinforcement of rubber: Perspective on the original polymer nanocomposite. *Polymers*, *13*(4), 538.

RED 4 MARS

Idea – one filler for many problems

Formulation

Ingredient	N330 [phr]	N330-C [phr]
Butadiene rubber	80	
Silicone rubber	20	
ZnO	3	
Stearic acid	3	
Sulfur	1.2	
CBS	1.6	
6PPD	2	
N330	37.5	
Trimethylolpropane tris(3-mercaptopropionate)	-	2

Mixing procedure

Mixing conditions Laboratory mixer 50 cm^3	
Temperature	70 °C
Temp. rise	70 °C → 90 °C
Time	4 min + 1 min with curatives
Rotor speed	20 rpm (incorporation), 60 rpm (homogenization)

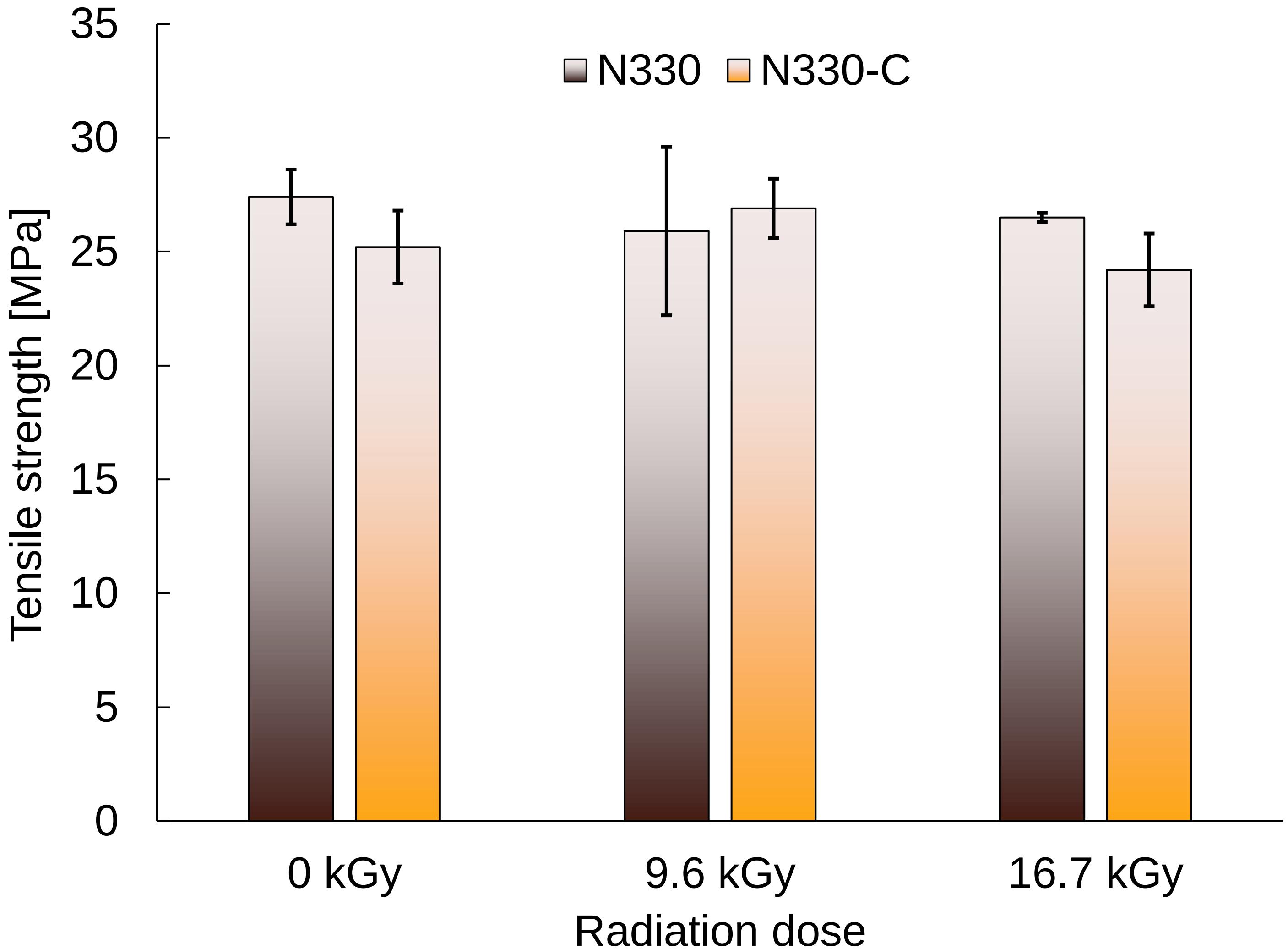
Idea – one filler for many problems

- Vulcanizates: γ-irradiated with doses of 9.6 kGy and 16.7 kGy

- First results: tensile properties tested before and after the irradiation at -40°C to simulate Mars' surface temperature, which on average equals -62.7 °C

Idea – one filler for many problems

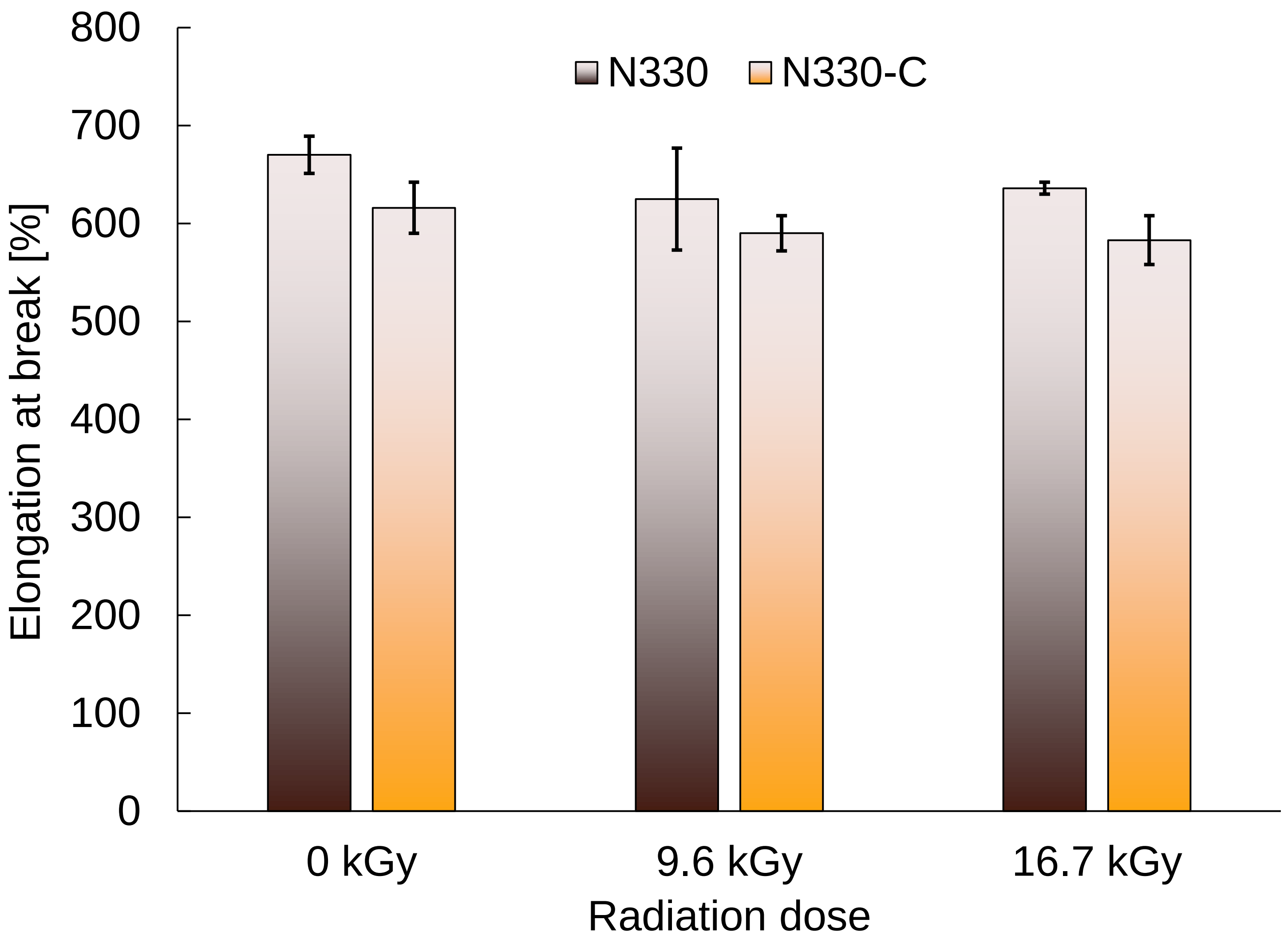
Tensile strength tested at -40°C



- Overall tendency: High tensile strengths achieved
- No significant impact of radiation
- No significant impact on the coupling agent

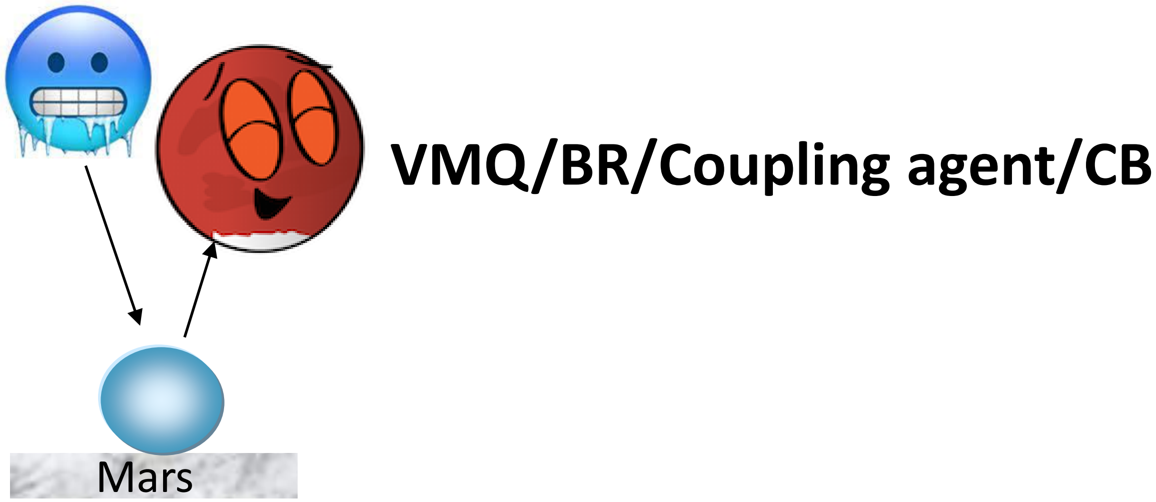
Idea – one filler for many problems

Elongation at break tested at -40°C



- Overall tendency: High elongation at break (Eab) achieved
- No significant impact of radiation, tendency to decrease Eab
- Impact of coupling agent: decreases Eab, probably due to higher crosslink density

How to design rubber for Mars?



How to remain elastic at such cold conditions with a higher radiation?

RED4 MARS

Summary

- Unique elastic and damping properties of rubber make it an advantageous material for Mars missions
- Crewed future missions to Mars will need rubber for critical applications
- Possible solution for low temperature on Mars: Blending BR with VMQ
- Improve compatibility of BR/VMQ blends by coupling agent
- Possible solution to face higher radiation on Mars: Addition of carbon black N330

Why?

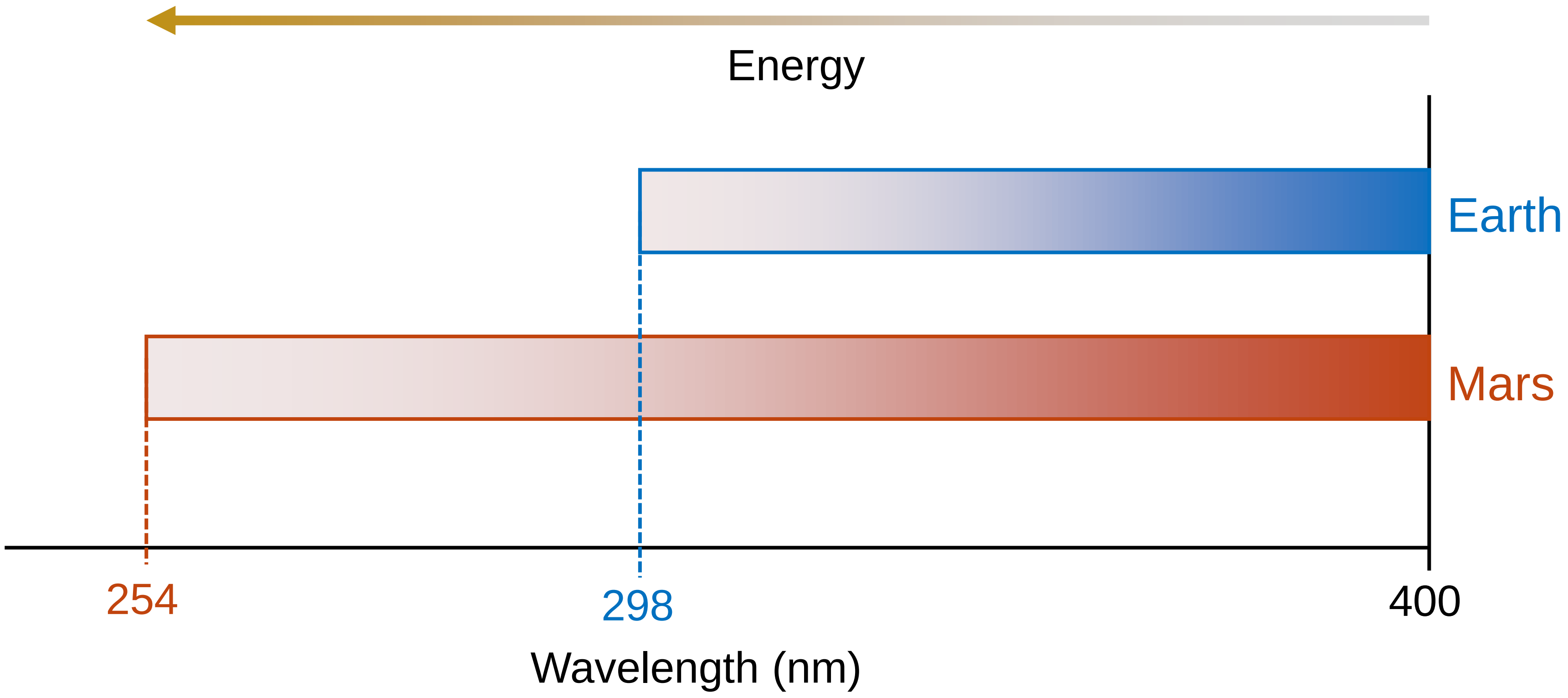
The first step is done.

What will come next?

https://www.planet-wissen.de/natur/weltall/mars/pwiewissensfrage400.html; https://www.space.com/47-mars-the-red-planet-fourth-planet-from-the-sun.html; https://www.space.com/16758-apollo-11-first-moon-landing.html

Outlook

! High-energy UV radiation due to the lack of an ozone layer

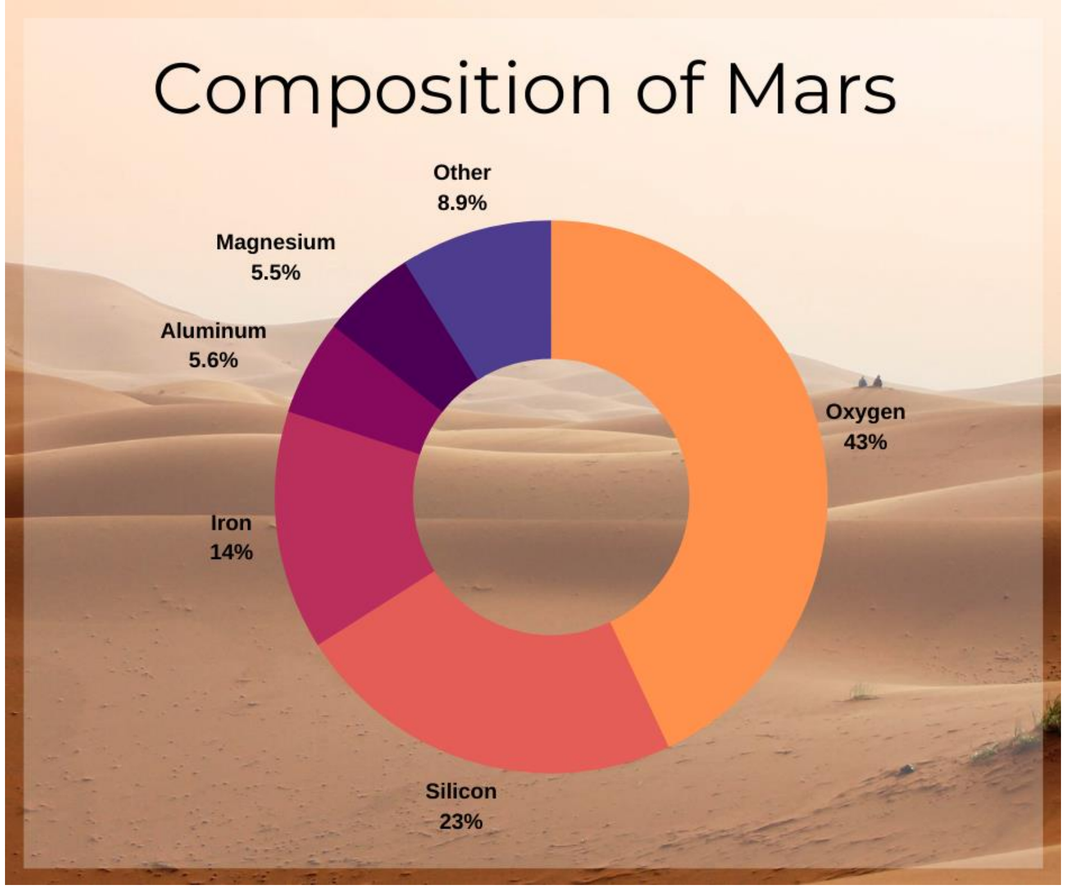


- UV testing of the designed rubber compounds

Khodadad, C. L., Wong, G. M., James, L. M., Thakrar, P. J., Lane, M. A., Catechis, J. A., & Smith, D. J. (2017). Stratosphere conditions inactivate bacterial endospores from a Mars spacecraft assembly facility. *Astrobiology*, *17*(4), 337-350.

Outlook

Can we use resources on Mars?



→ Martian regolith contain >40 % of SiO_2

↓ Extraction and precipitation in form of reinforcing silica

- Investigation of possible synthesis of reinforcing silica from Mars regolith for In-Situ Resource Utilization

https://www.marssociety.ca/2020/09/02/isru-part2/

https://www.ppgsilica.com/FAQs.aspx

The results and experience gathered within the RED 4 MARS project will allow to look into other space environments:

- The Moon's surface:

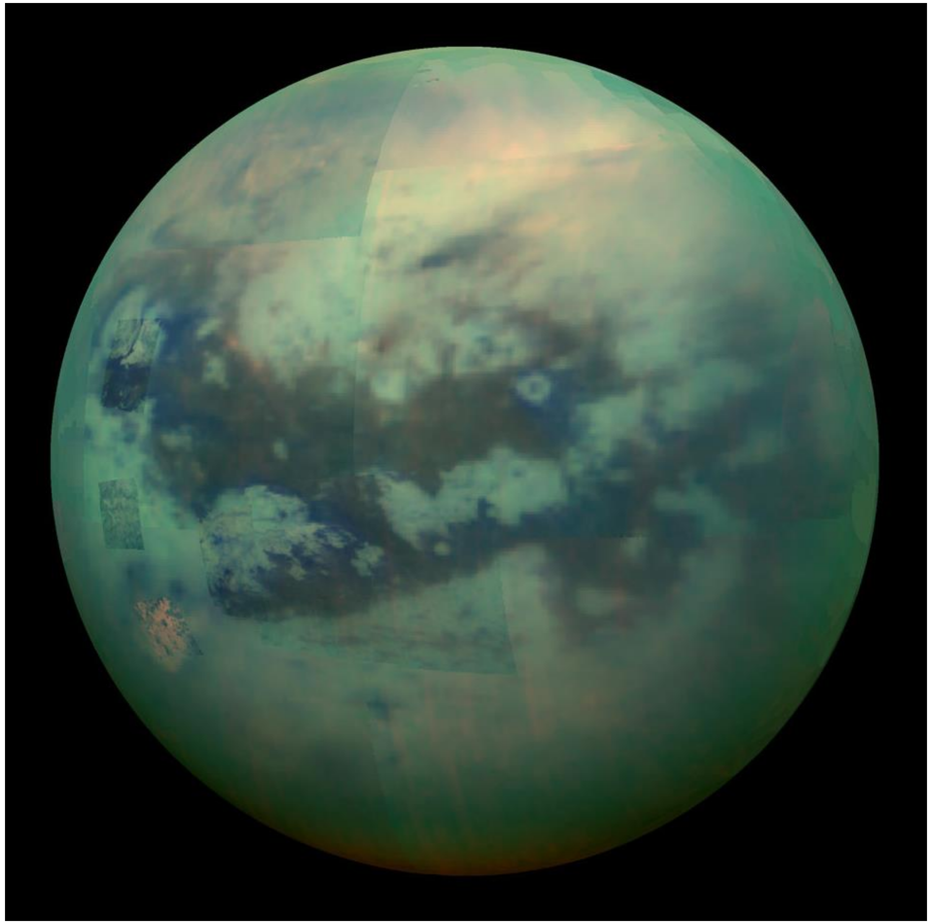
- *Permanent base planned by ESA and NASA*
- *Temperature range -150°C – 100°C*
- *Vacuum – no atmosphere = outgassing*
- *Direct exposition to radiation*
- *Permanent plasma*
- *Abrasive, static-charged particles*

https://en.wikipedia.org/wiki/Moon#/media/File:FullMoon2010.jpg

Bringing rubber into space

The results and experience gathered within the RED 4 MARS project will allow to look into other space environments:

- Titan – Saturn's moon
- *Submarine mission planned by NASA*
- *Temperature -180°C*
- *Pressure about 50 % higher than on Earth*
- *Lakes of liquid hydrocarbon*
- *Unknown conditions in the lakes*



https://www.npr.org/sections/13.7/2017/10/16/555045041/confession-of-a-planetary-scientist-i-do-not-want-to-live-on-mars

Stay tuned!

*“**R**ubber & **E**lastomer **D**evelopment for **MA**rtian envi**R**onmental application**S** (**RED 4 MARS**)”*

RED 4 MARS

RED 4 MARS

I·M3 Institute of Materials, Minerals & Mining

This project is financed by EU Marie Skłodowska Curie Action:
Global Fellowship. Grant No. 101025756

Thank you for your kind attention!

Lodz University of Technology

UNIVERSITY OF TWENTE.

THE UNIVERSITY OF AKRON · FIAT LUX · 1870