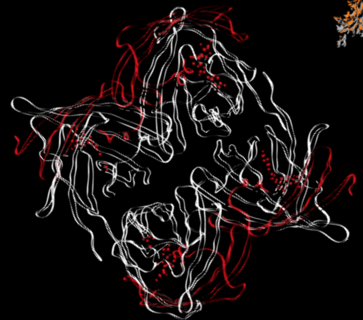
tire technology EXPO 2020

# Will Martian rovers ever run on rubber tires?

**Rafal Anyszka, Anke Blume**



University of Twente, Faculty of Engineering Technology, Department of Mechanics of Solids, Surfaces & Systems (MS3),
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UNIVERSITY OF TWENTE.

Elastomer Technology and Engineering

# Current solutions


Manual controlling from Earth: average 20 min signal delay + Fragile equipment + Low elasticity

**Low speed**

- Martian rovers use **aluminum-based wheels** instead of **rubber tires**
- Aluminum exhibits much better **resistance to Martian environment** than rubber: superior aging resistance = higher wheel reliability
- Martian rovers carry **sensitive equipment** that can **suffer from** intensive **vibration** during driving
- Aluminum exhibits **low flexibility and damping** properties

https://www.reddit.com/r/space/comments/2dj1xb/comparative_wheel_sizes_of_mars_rovers/
https://i.stack.imgur.com/HejZ8.jpg
https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/ExoMars/Moving_on_Mars

# Current solutions


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**Low speed**

# 2020 missions


**ExoMars**
(ESA/Roscosmos)

New flexibility improved design.
The alloy is able to bend.

**Mars 2020**
(NASA)


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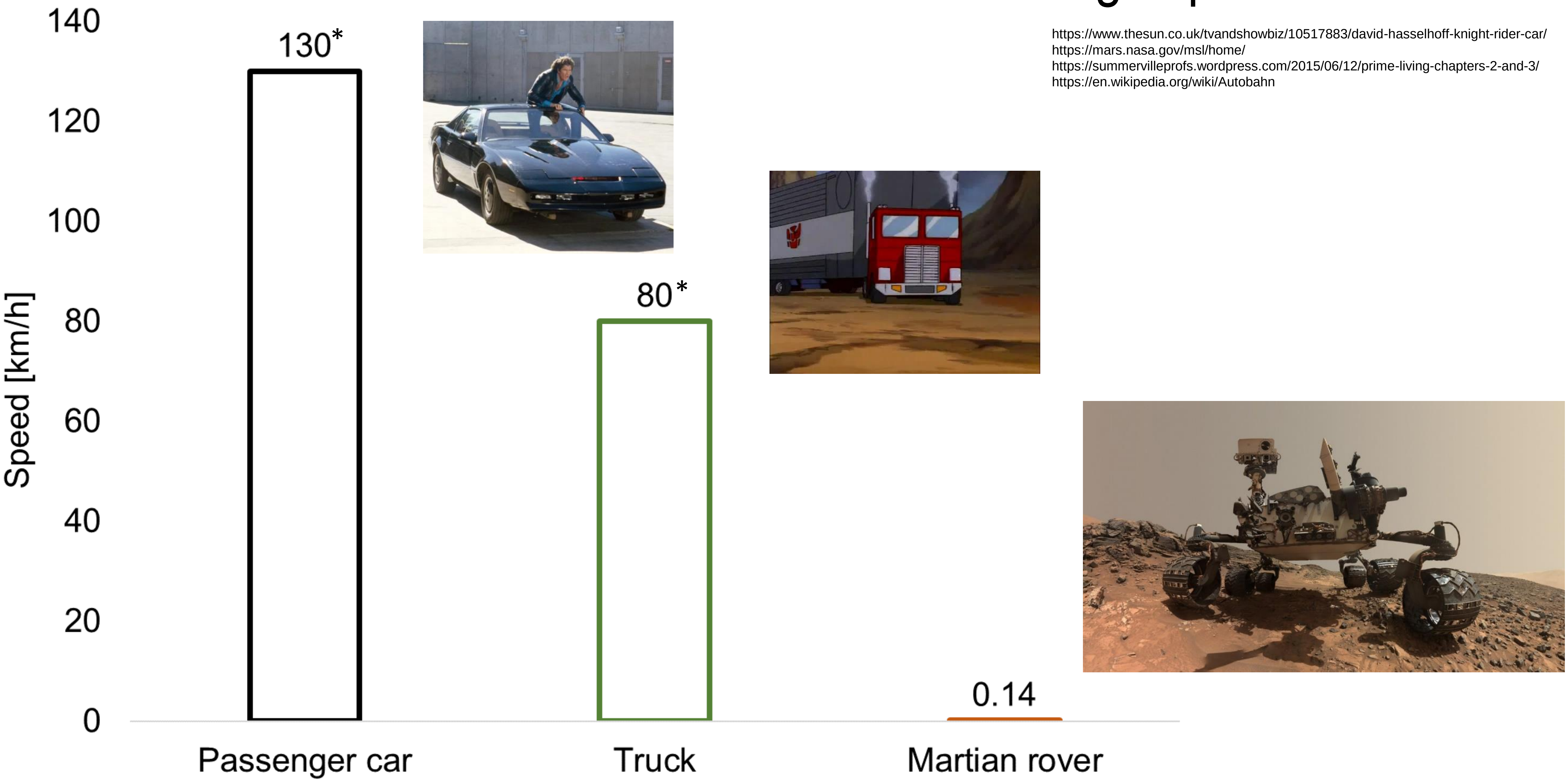
# Average speed of vehicles

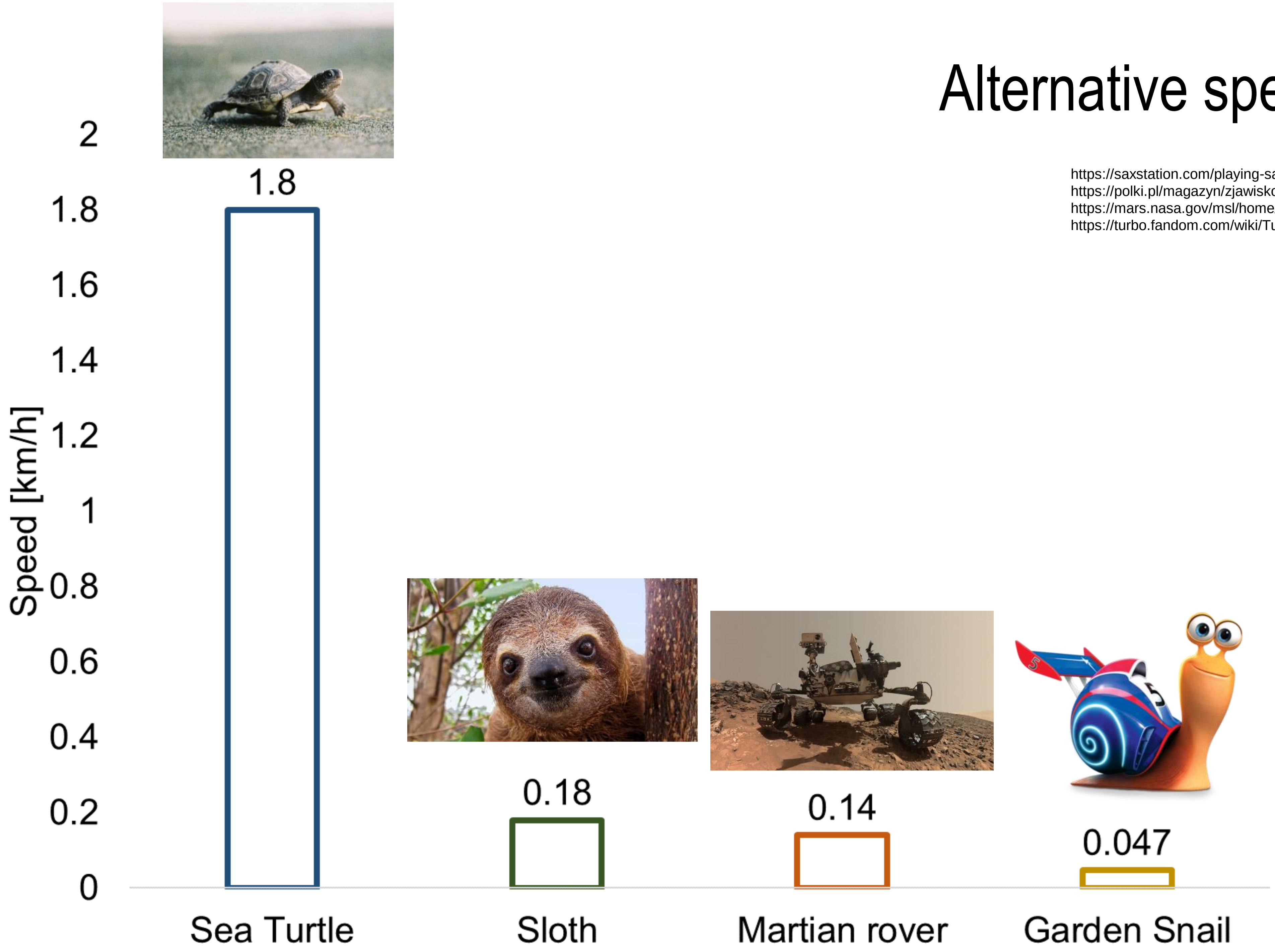
https://www.thesun.co.uk/tvandshowbiz/10517883/david-hasselhoff-knight-rider-car/
https://mars.nasa.gov/msl/home/
https://summervilleprofs.wordpress.com/2015/06/12/prime-living-chapters-2-and-3/
https://en.wikipedia.org/wiki/Autobahn

*General speed limitation on German highways

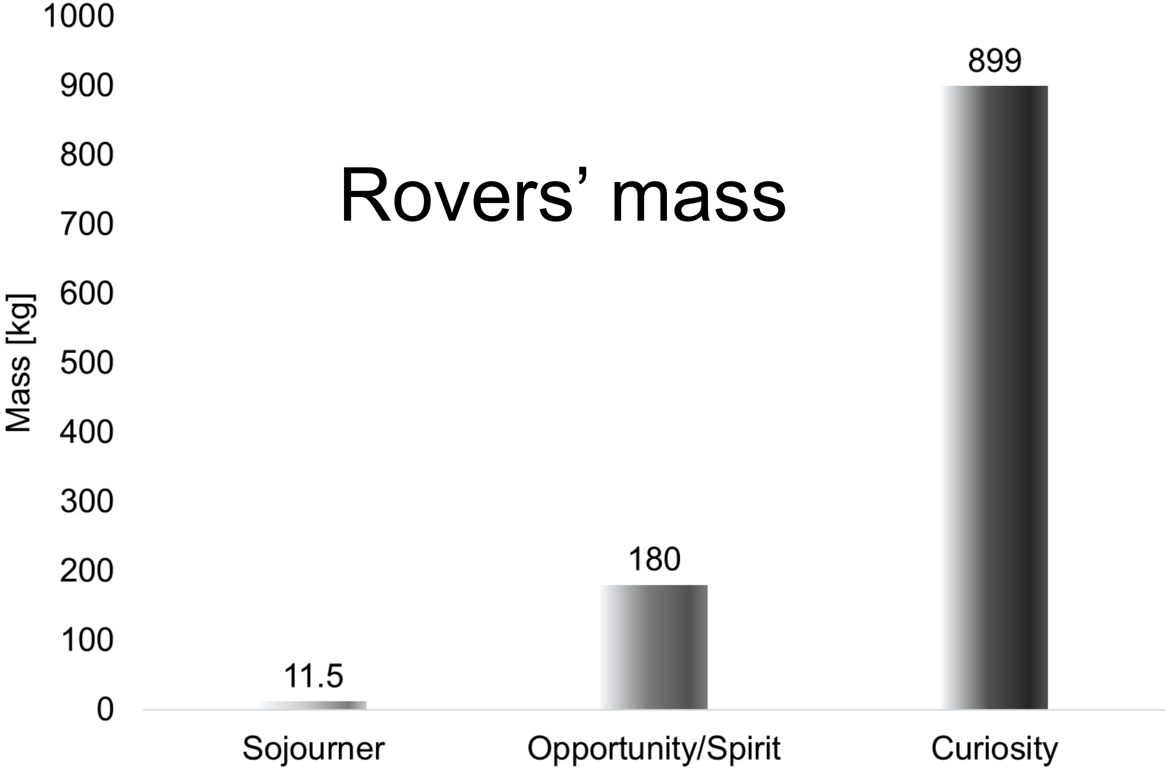


# Alternative speed comparison

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)



# Curiosity rover wheel damage




- Too low resistance to continuous deformation – low elasticity
- Direct contact with sharp/pointy rocks

https://www.spaceflightinsider.com/missions/solar-system/wheel-treads-break-curiosity-rover/
https://spacenews.com/mars-rover-curiosity-dealing-with-wheel-damage/
https://www.space.com/26472-mars-rover-curiosity-wheel-damage.html

# Self-driving rovers for Martian missions

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

- ➢ No need to control from Earth = Maximum speed can be increased

- ❖ Higher speed will accelerate the fatigue of wheels
- ❖ Damping properties have to be improved to protect the sensitive equipment

*From the beginning of 2019 ESA is testing a self driving software for Martian rovers*


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

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## Let's try to use rubber!

nsitive equipment

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# How about high performance vehicles on Mars?

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

# 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 – 3.0 mSv/a | High – 400-500 mSv/a; additionally occasional solar proton events |
| Atmosphere | 21 % oxygen;<br>78 % nitrogen;<br>1 % other | 96 % carbon dioxide;<br><2 % argon;<br><2% nitrogen;<br><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/

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| Atmosphere | 21 % oxygen; 78 % nitrogen; 1 % other | 96 % carbon dioxide; <1% other |

**Very small amount of oxygen**
**=**
**less oxidation aging**

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https://solarsystem.nasa.gov/planets/mars/in-depth/
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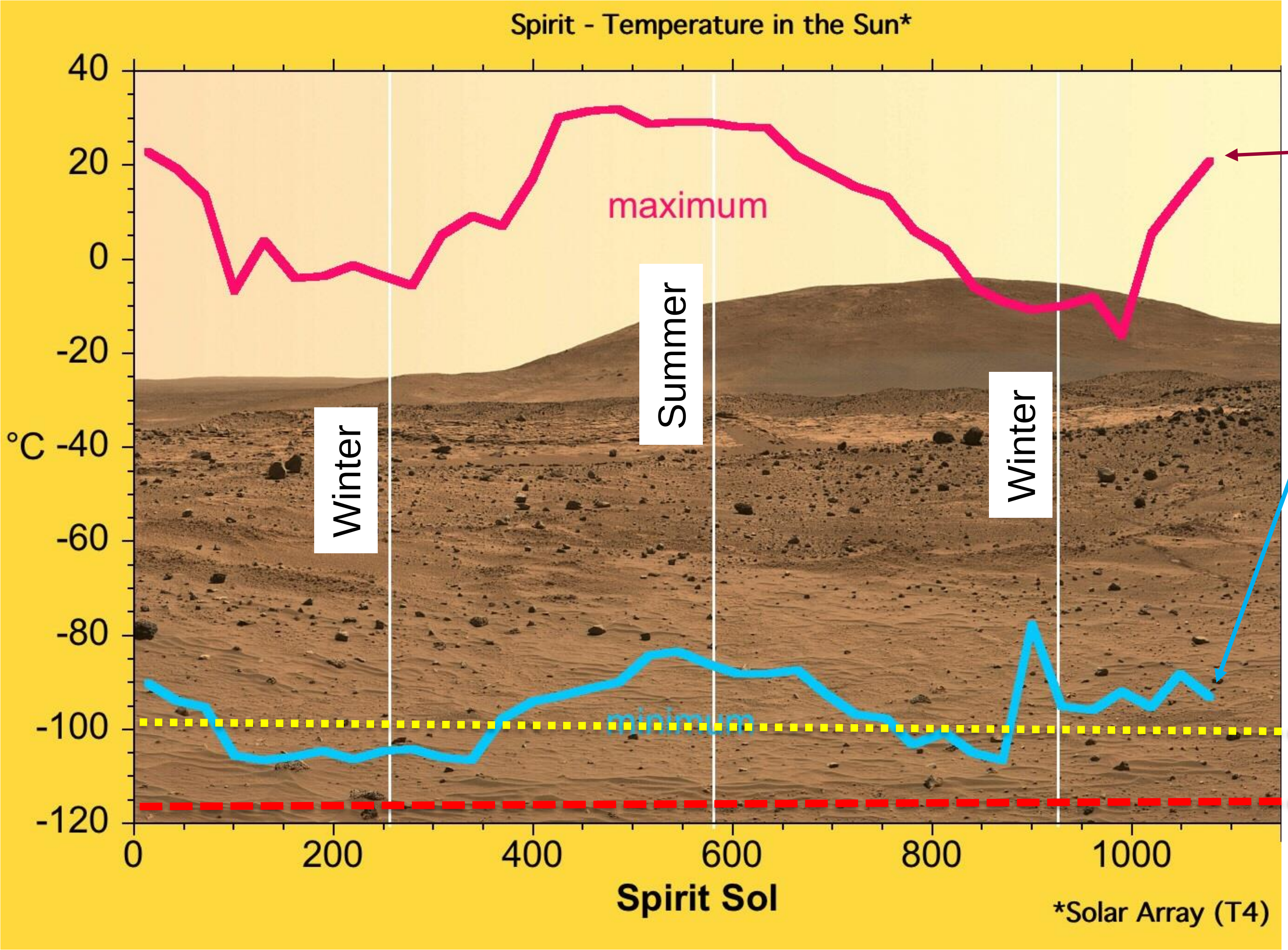
# Can the rubber flexibility be preserved on Mars?




Maximum

Minimum

Glass transition temperature

Butadiene rubber

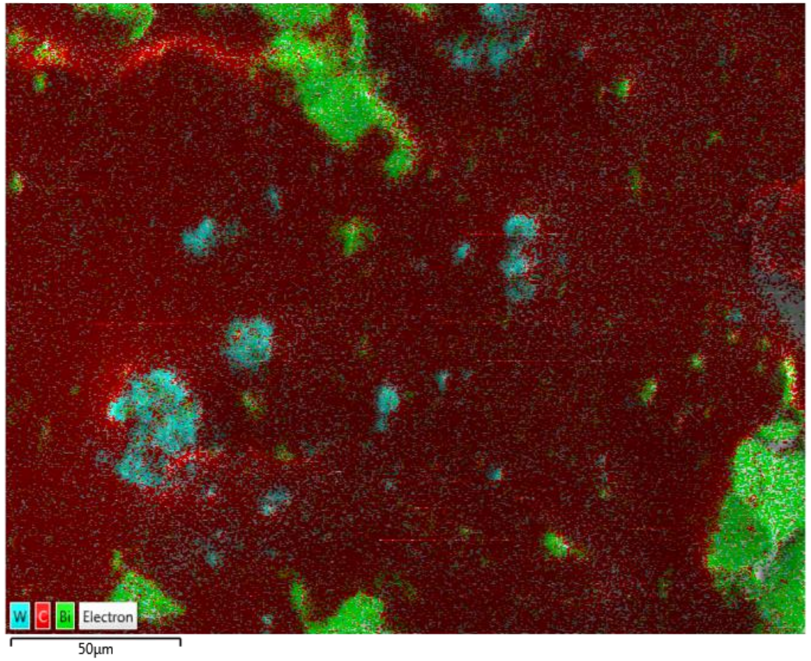
Silicone rubber

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

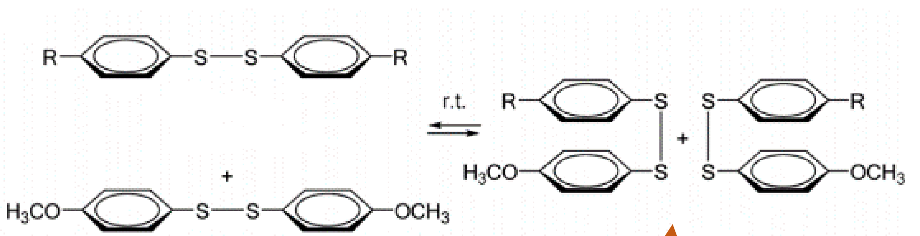
# Improving radiation resistance of rubber

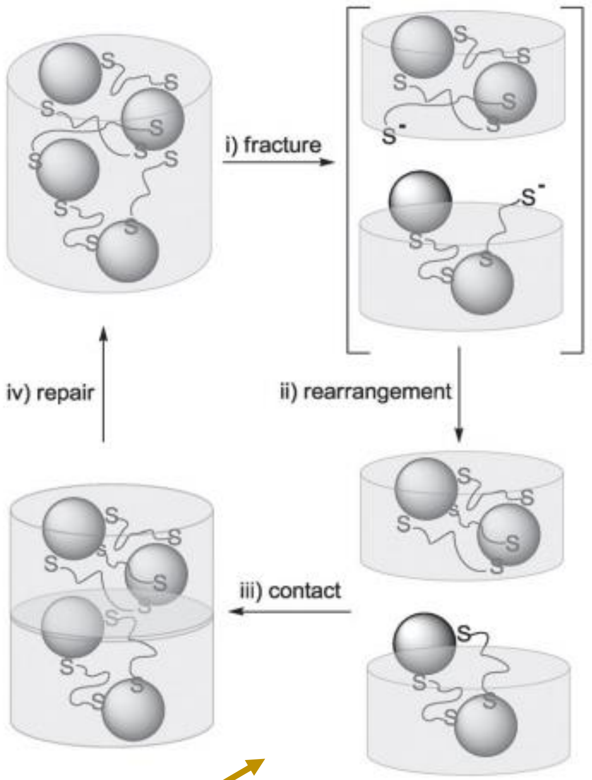
- Shielding effect
  - radiation shielding fillers: lead-, bismuth-, tungsten-oxide nanopowders

**Bi, W** particles in radiation shielding rubber composite




- Self healing solutions
  - Thiol-ene reversible bonds
  - Aromatic disulfide methathesis




Already studied for silicone rubber

Break of a bond:
possible recombination with a random aromatic sulfide

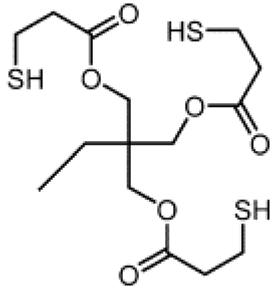
Martín, R., Rekondo, A., Echeberria, J., Cabañero, G., Grande, H. J., & Odriozola, I. (2012). Room temperature self-healing power of silicone elastomers having silver nanoparticles as crosslinkers. Chemical Communications, 48(66), 8255-8257. DOI: 10.1039/C2CC32030D
Rekondo, A., Martin, R., de Luzuriaga, A. R., Cabañero, G., Grande, H. J., & Odriozola, I. (2014). Catalyst-free room-temperature self-healing elastomers based on aromatic disulfide metathesis. Materials Horizons, 1(2), 237-240. DOI: 10.1039/C3MH00061C

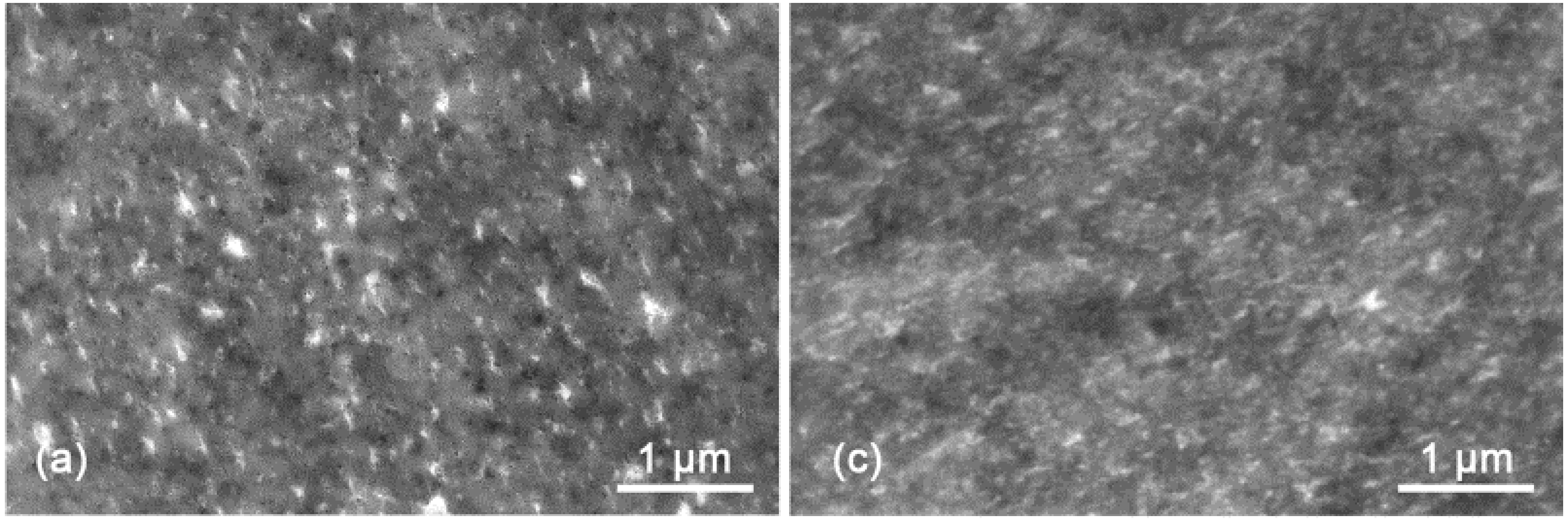
# Idea – blending of VMQ & BR

- **BR** as the continuous phase will provide better **mechanical** and **abrasion resistance**
- **VMQ** as the dispersed phase will provide better **low temperature resistance**

- But: Silicone rubber exhibits **limited miscibility** with organic rubbers
- Application of a compatibilizer is required

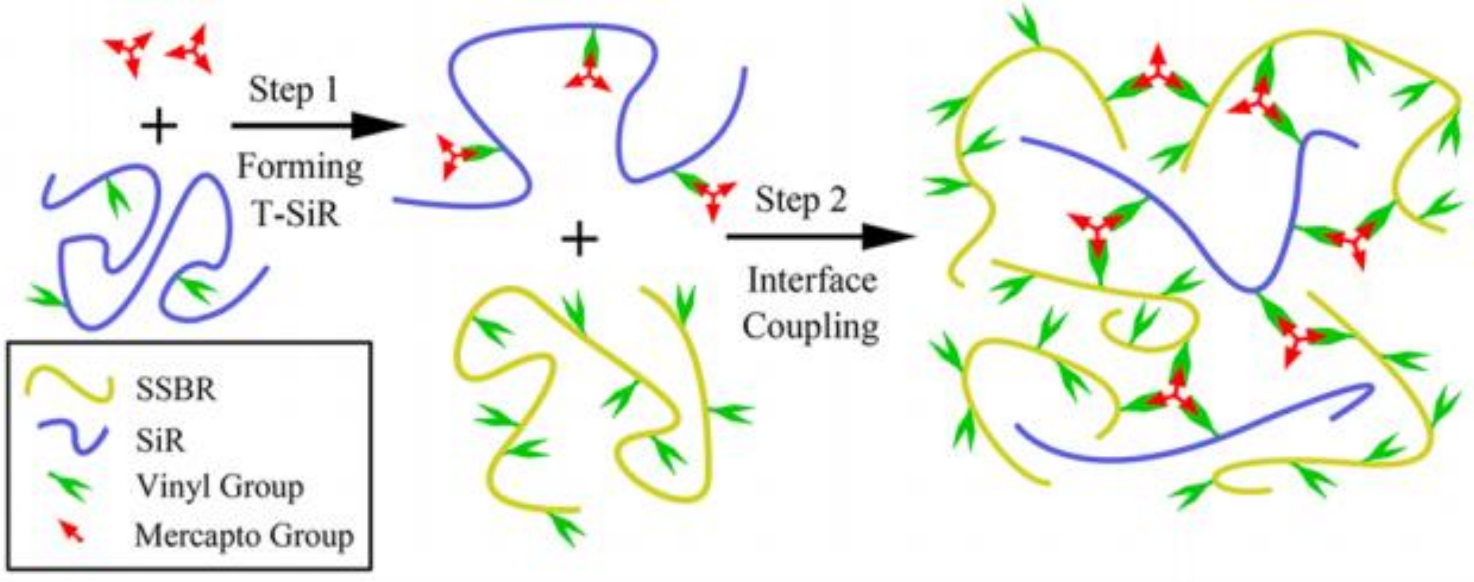
SSBR/VMQ (80/20) blends filled with:
(a) reference
(c) 4 phr trimethylolpropane tris(3-mercaptopropionate)




Li, M., Li, Y., Zhang, J., & Feng, S. (2014). Effect of compatibilizers on the miscibility of natural rubber/silicone rubber blends. Polymer Engineering & Science, 54(2), 355-363.

# Improving VMQ compatibility with organic rubber

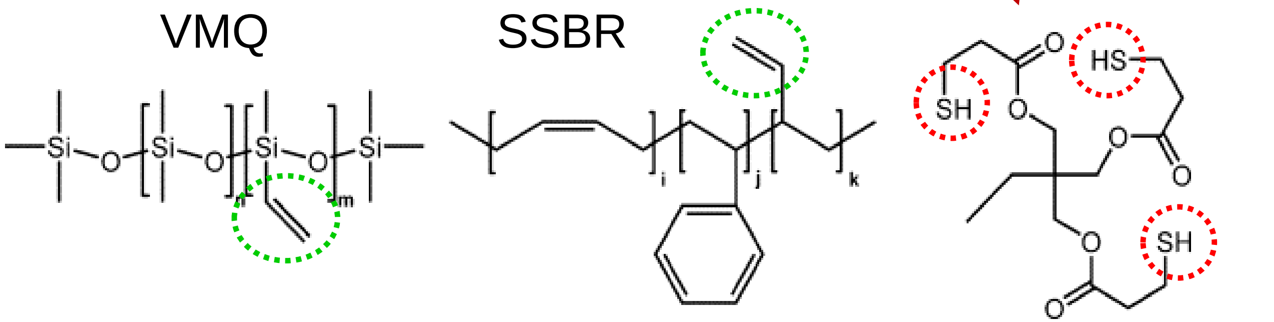



Trimethylolpropane tris(3-mercaptopropionate)

## Materials

VMQ

SSBR




Sun, Z., Huang, Q., Wang, Y., Zhang, L., & Wu, Y. (2017). Structure and properties of silicone rubber/styrene–butadiene rubber blends with in situ interface coupling by thiol-ene click reaction. *Industrial & Engineering Chemistry Research*, *56*(6), 1471-1477. DOI: 10.1021/acs.iecr.6b04146

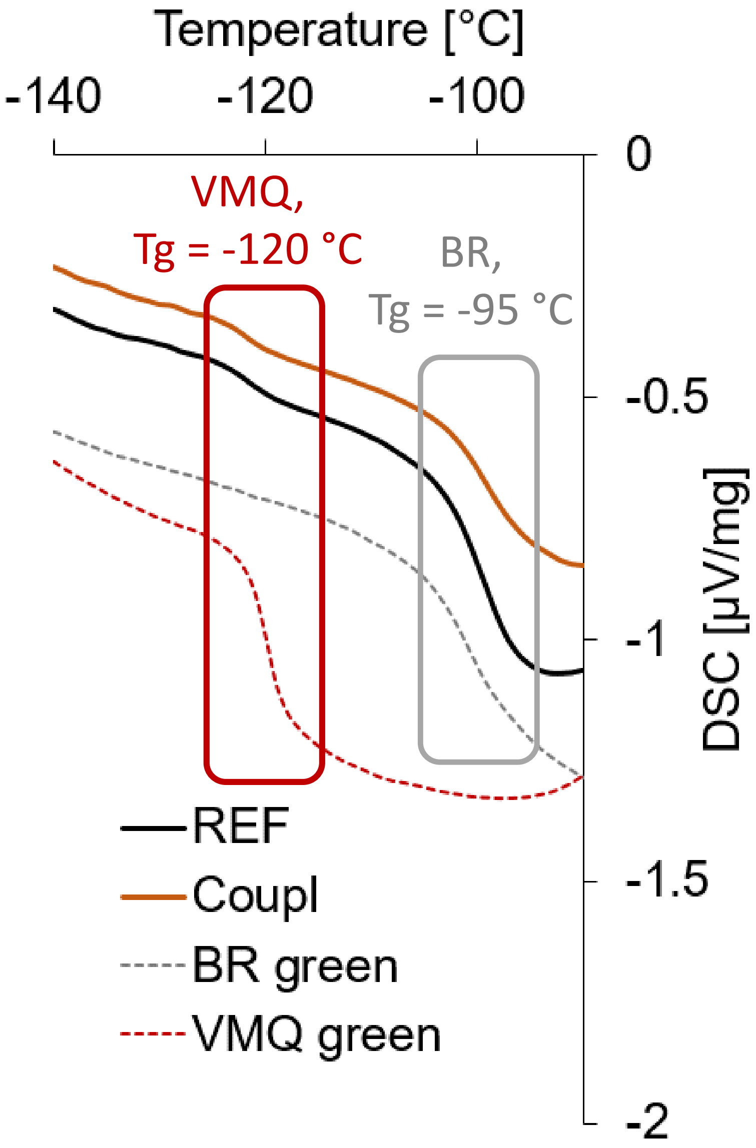
# Improving VMQ compatibility with organic rubber – own study

## Formulation

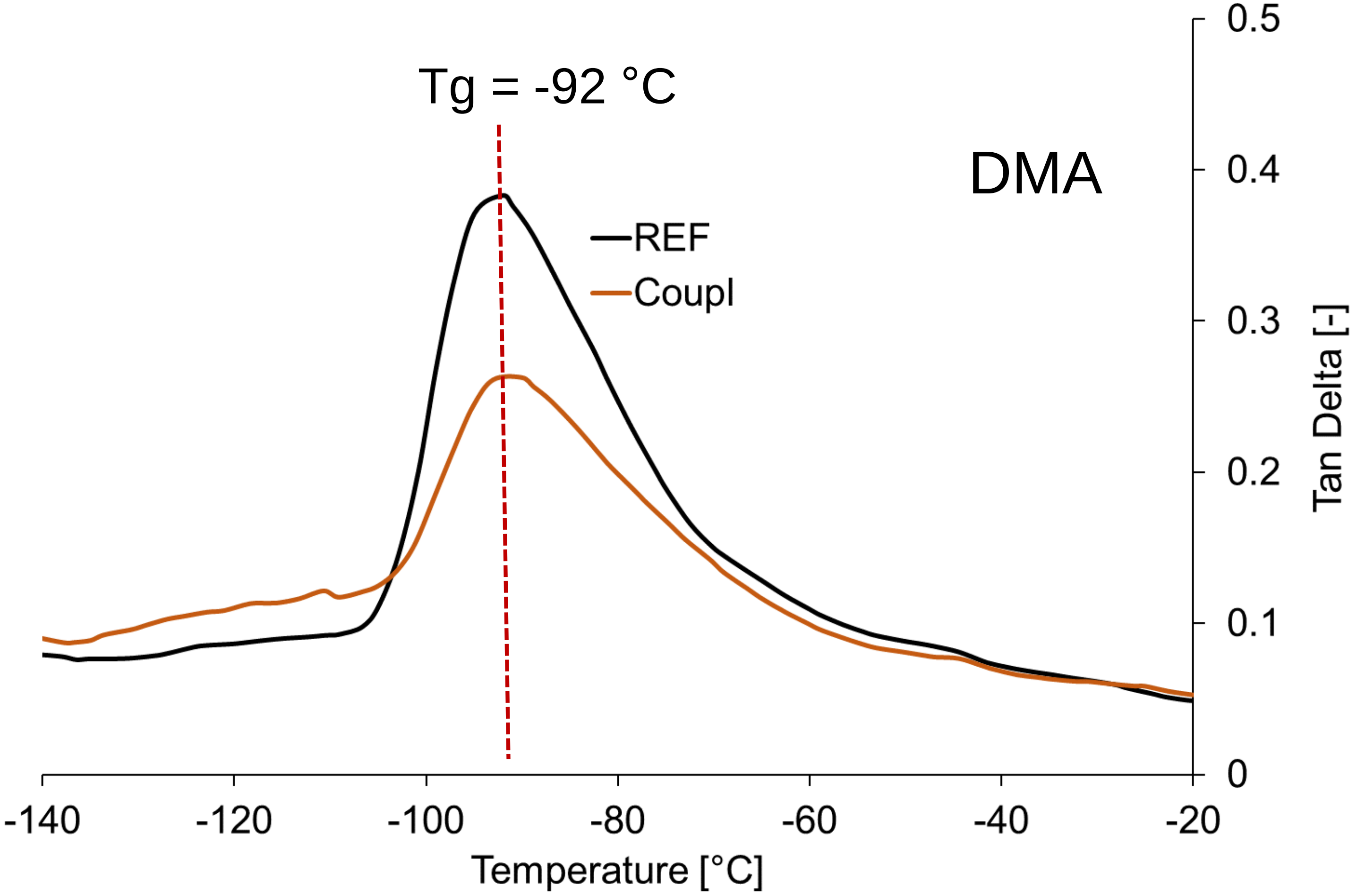
| Ingredient | REF [phr] | Coupl [phr] |
|---|---|---|
| Butadiene rubber | 80 | 80 |
| Silicone rubber | 20 | 20 |
| ZnO | 5 | 5 |
| Stearic acid | 3 | 3 |
| Sulfur | 1.2 | 1.2 |
| CBS | 1.6 | 1.6 |
| Trimethylolpropane tris(3-mercaptopropionate) | - | 4 |

| 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) |

# Improving VMQ compatibility with organic rubber – own study

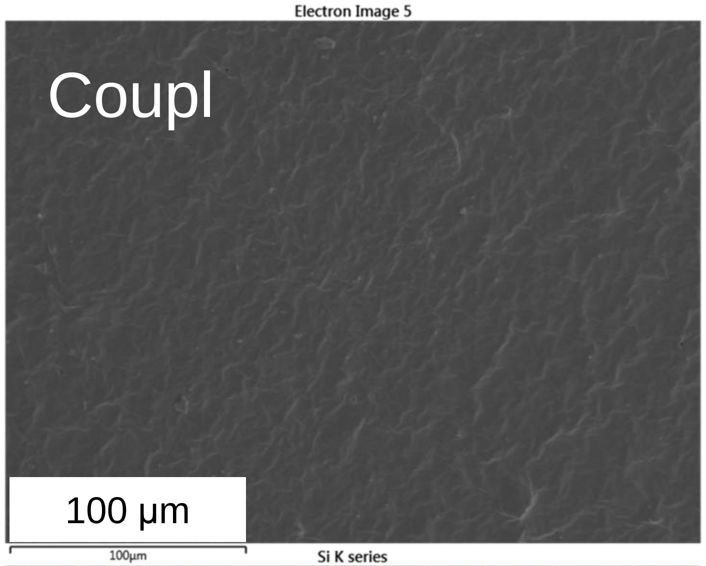


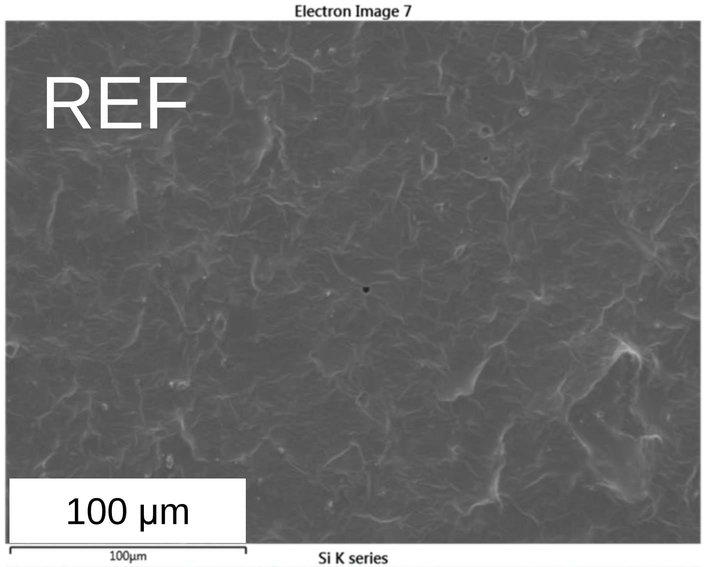

DSC and DMA investigation of the glass transition temperature of the blends



# Improving VMQ compatibility with organic rubber – own study

SEM

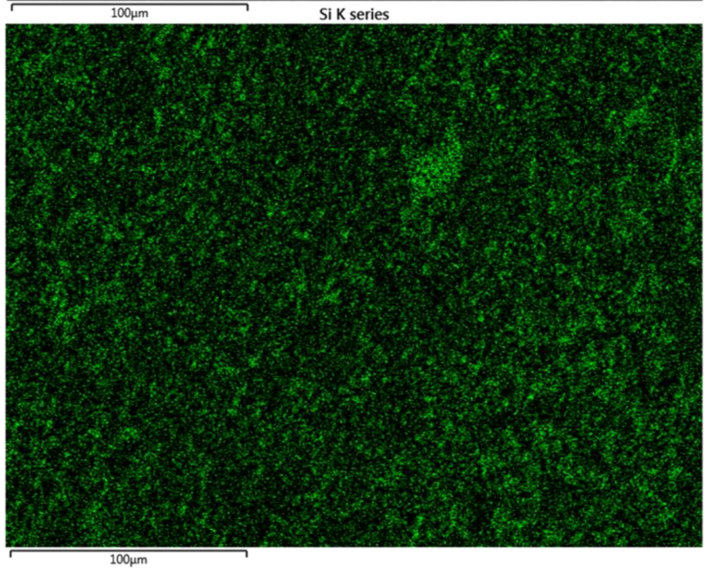


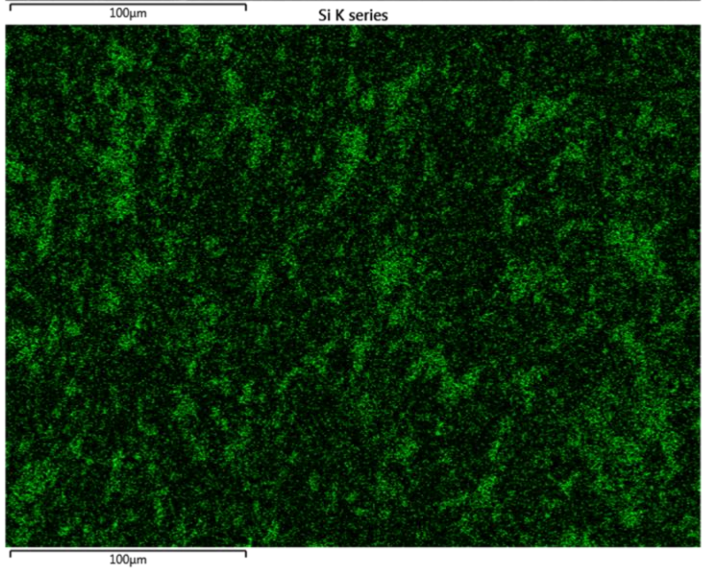




Micromorphology investigation

EDX

**Si** mapping




Significant improvement in the silicone rubber dispersion

# Summary

- Increase of Martian rover’s mass + self driving software = new wheel design of higher fatigue and damping properties that withstand higher rover speed
- Rubber can be a promising material for the new Martian rovers’ wheels if its radiation resistance and low temperature flexibility are improved
- Silicone & butadiene rubber blends might be suitable
- Compatibility of the silicone & butadiene rubber can be improved by addition of trimethylopropane tris(3-mercaptopropionate)
- Radiation resistance of the rubber can be improved by application of self healing materials and shielding fillers

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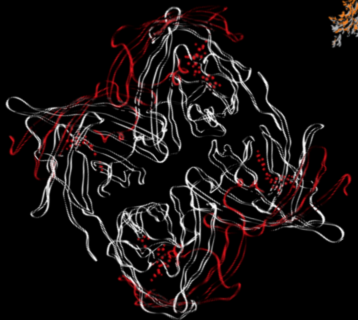

# Thank you for your kind attention!

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