RED 4 MARS

Rubber for Mars: Optimization of BR/VMQ compounds

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Current solutions

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

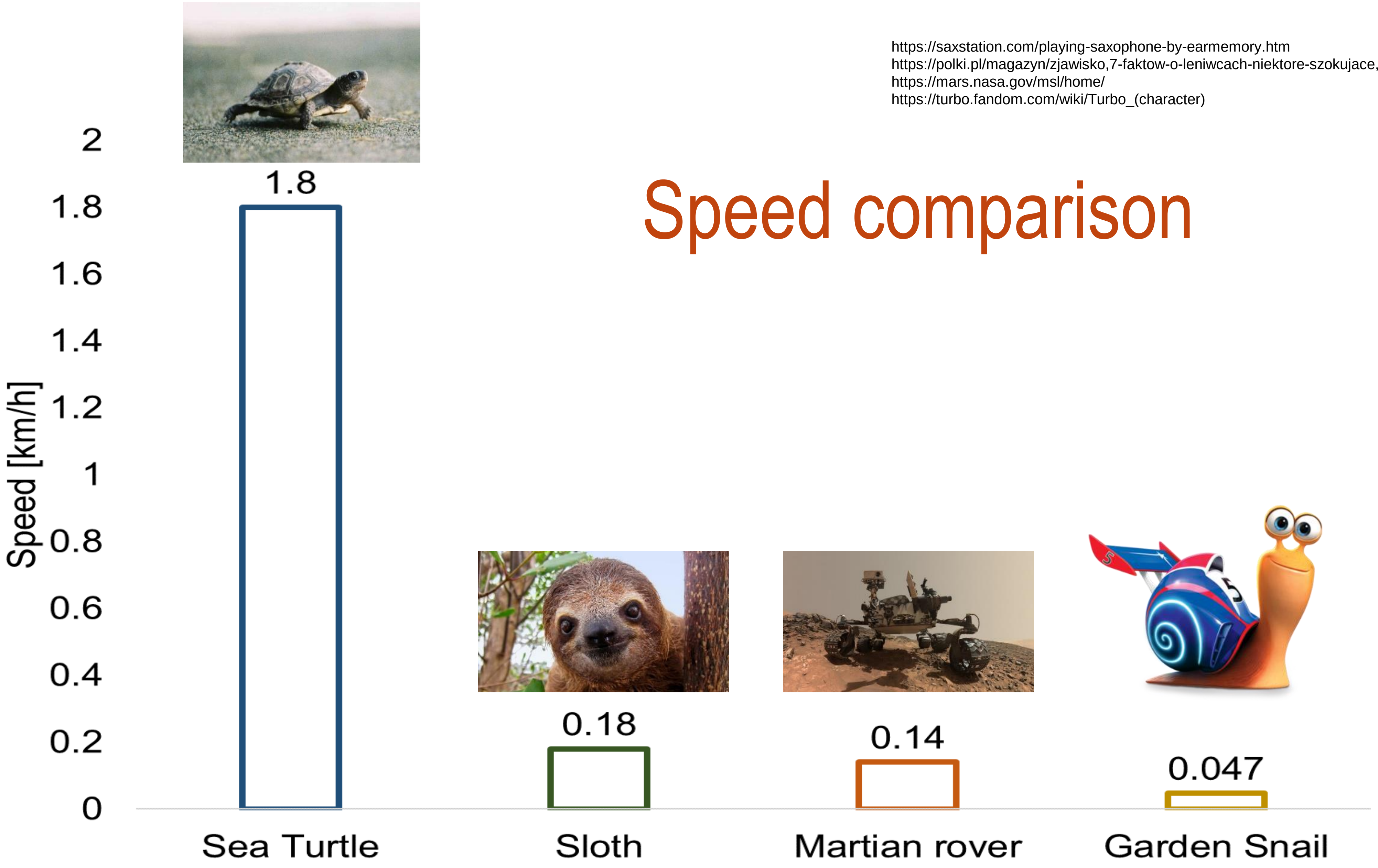
Low speed

- ✓ Mars rovers use **aluminum wheels**
- ✓ Aluminum exhibits good **resistance to Martian environment** = higher wheel reliability
- ✓ Rubber tires are **much heavier** than thin aluminum wheels
- ✗ Martian rovers carry **sensitive equipment** that can **suffer from** intensive **vibration** during driving
- ✗ Aluminum exhibits **low flexibility and damping** properties

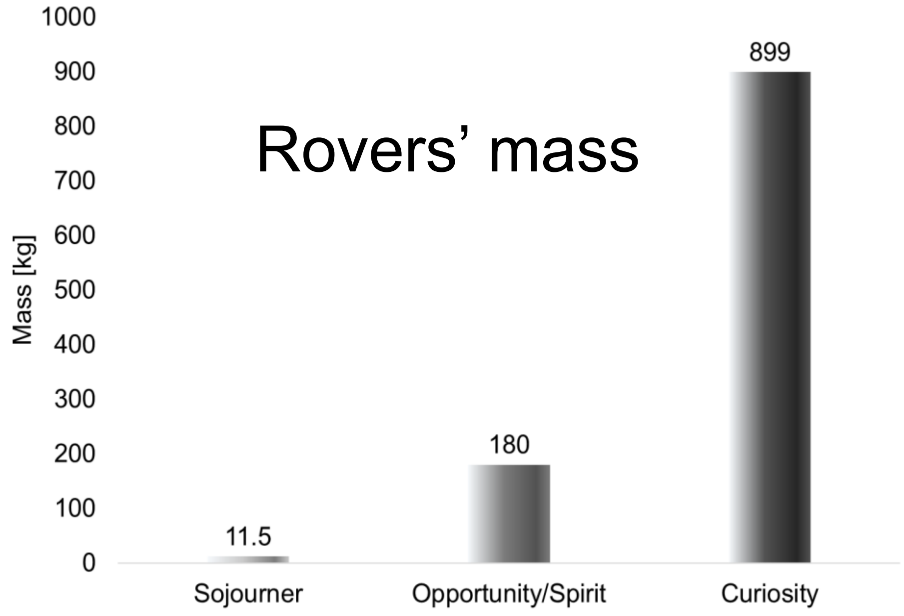
https://www.reddit.com/r/space/comments/2dj1xb/comparative_wheel_sizes_of_mars_rovers/
https://i.stack.imgur.com/HejZ8.jpg
https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/ExoMars/Moving_on_Mars

Current solutions

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

How about high-performance vehicles on Mars?

Let’s try to use rubber!

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

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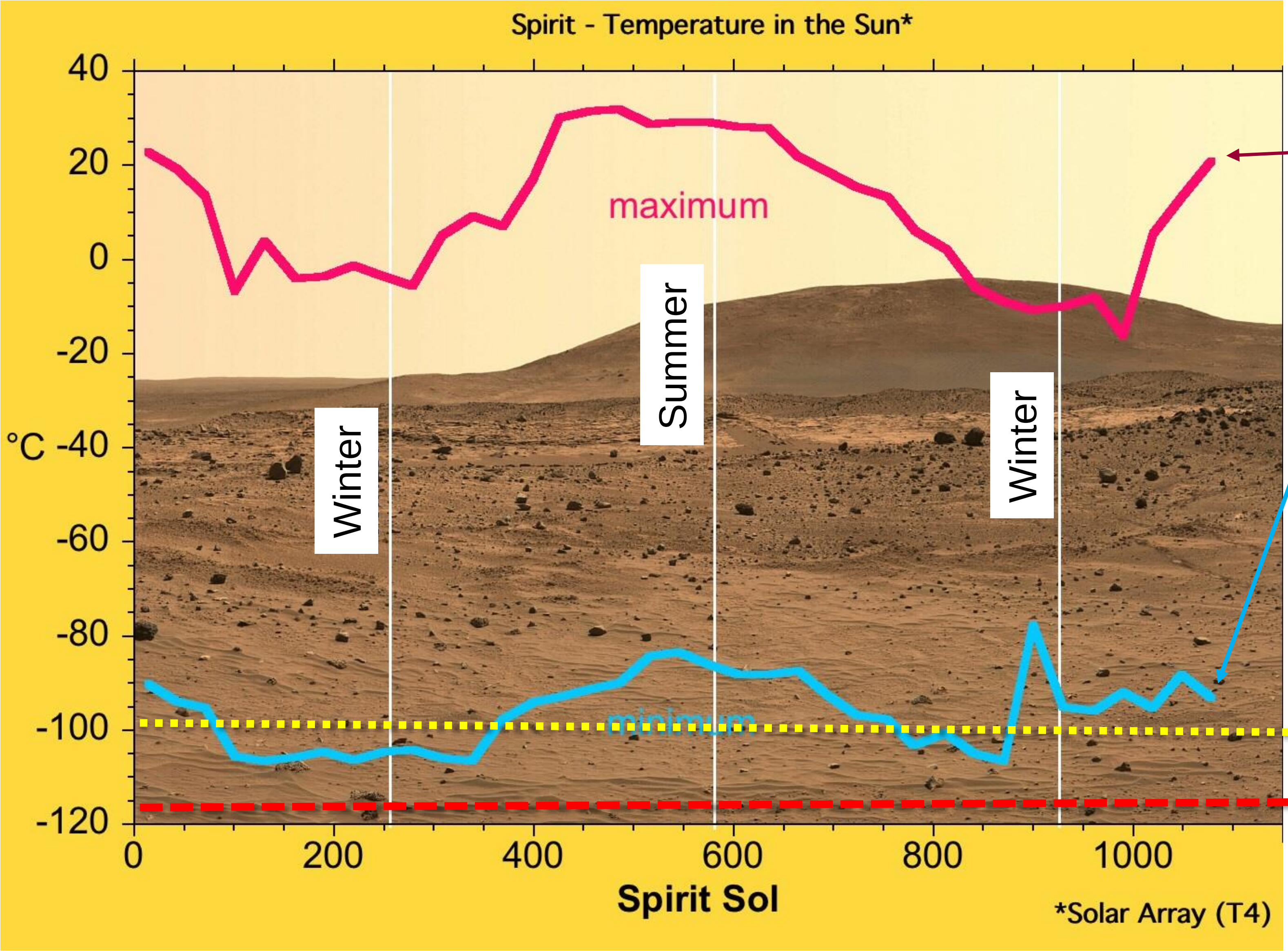
Can the rubber flexibility be preserved on Mars?



Maximum

Minimum

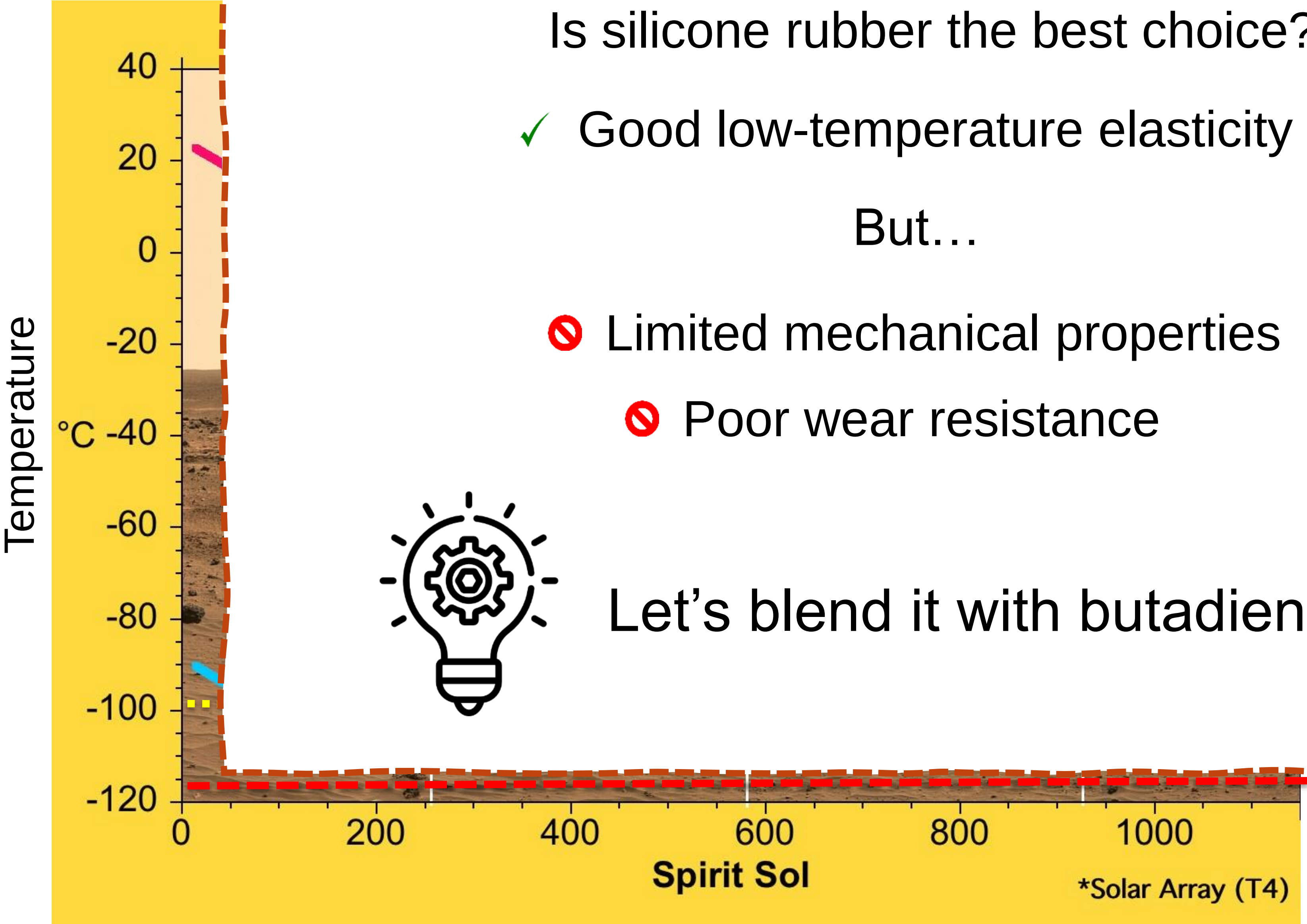
Glass transition temperature

Butadiene rubber

Silicone rubber

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

Can the rubber flexibility be preserved on Mars?



Is silicone rubber the best choice?

✓ Good low-temperature elasticity

But…

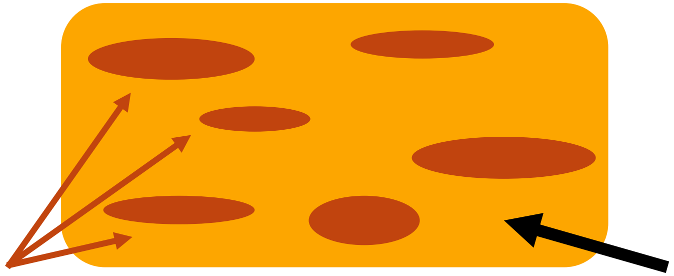
- 🚫 Limited mechanical properties
- 🚫 Poor wear resistance

Let's blend it with butadiene rubber!

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

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

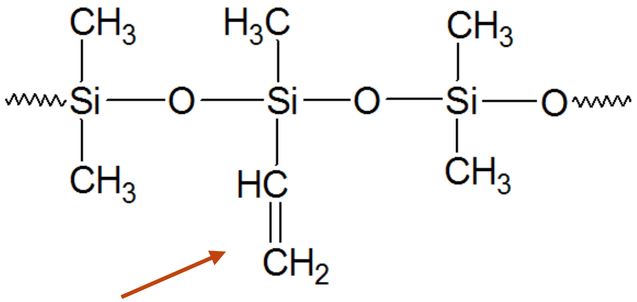
Morphology of the designed rubber compounds



Dispersed phase
Vinyl-Methyl Silicone Rubber (VMQ):
- ✓ Very good low temperature elasticity
- ✓ Good UV resistance
- ✗ Low abrasion resistance
- ✗ Low mechanical properties

Continuous phase
Butadiene Rubber (BR):
- ✓ Good low-temperature elasticity
- ✓ High abrasion resistance
- ✓ High mechanical properties
- ✗ Low UV resistance

Polimer MV 1,0



1% of methyl-vinyl

Buna CB24 > 96% of cis-mers

Addition of reinforcing fillers:

♠Carbon Black N330 – 78 m^2/g

♦Silica ULTRASIL® 7000 GR – 170 m^2/g + TESPD silane (Si®266)

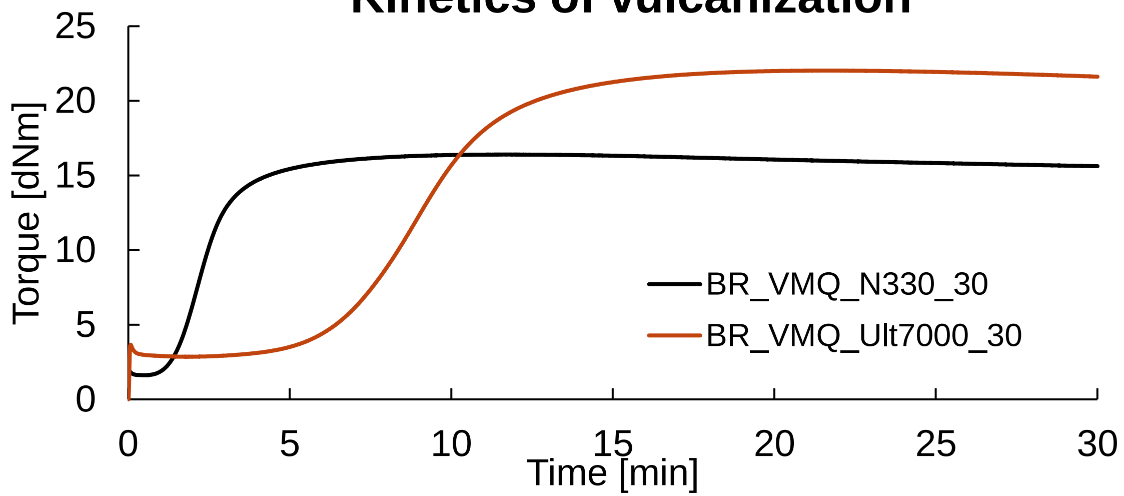
Choosing the right filler

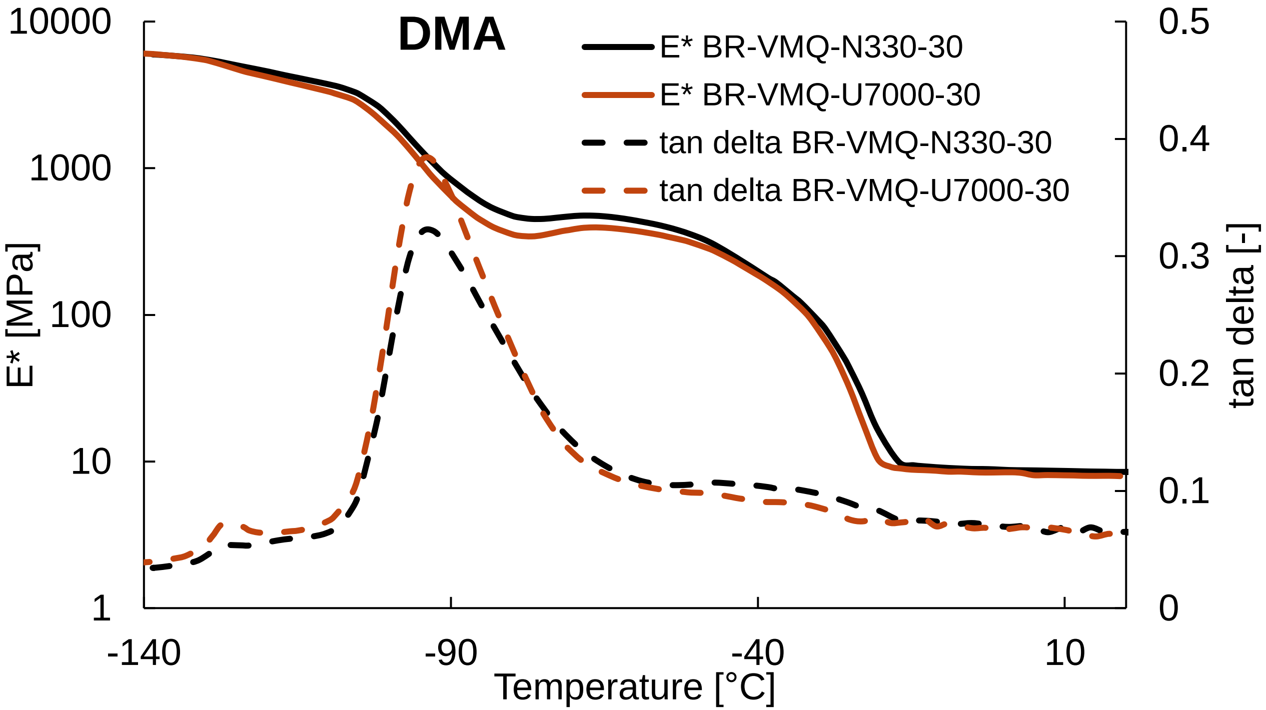
Formulation of the compounds

Samples / Ingredients [phr]	BR-VMQ_CBN330_30	BR-VMQ_SilUlt7000_30
BR (Buna CB24)	**80**	
VMQ (Polimer MV 1,0)	**20**	
CB N330	**30**	**-**
Silica ULTRASIL® 7000 GR	**-**	**30**
TESPD silane (Si® 266)	**-**	**3**

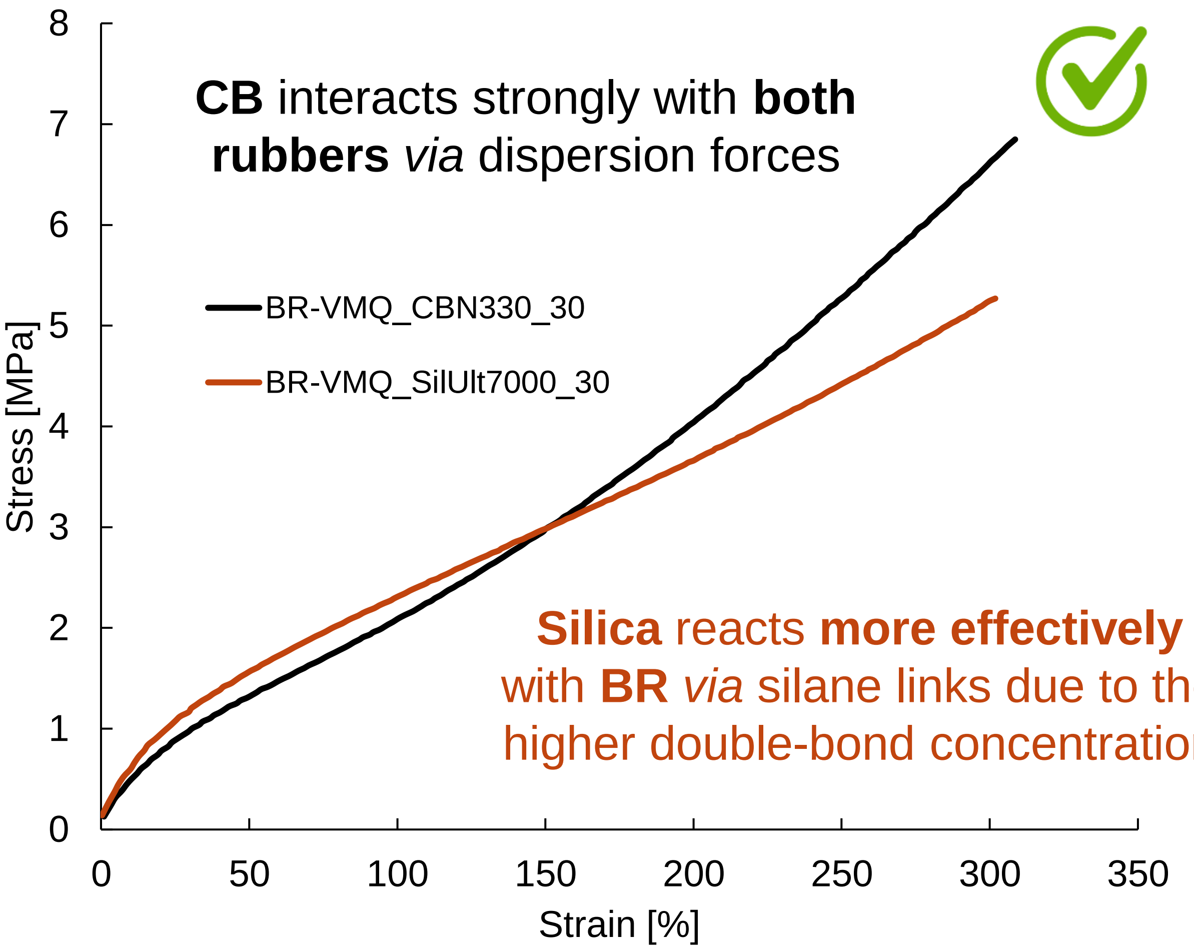
Other ingredients [phr]:
Vulcanization activators: Zinc oxide – **3**; Stearic acid – **3**
Vulcanization accelerator: N-cyclohexyl-2-benzothiazole sulfenamide (CBS) – **1.6**
Vulcanization agent: Sulfur – **1.2**
Antiozonant: N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD) - **2**

Choosing the right filler





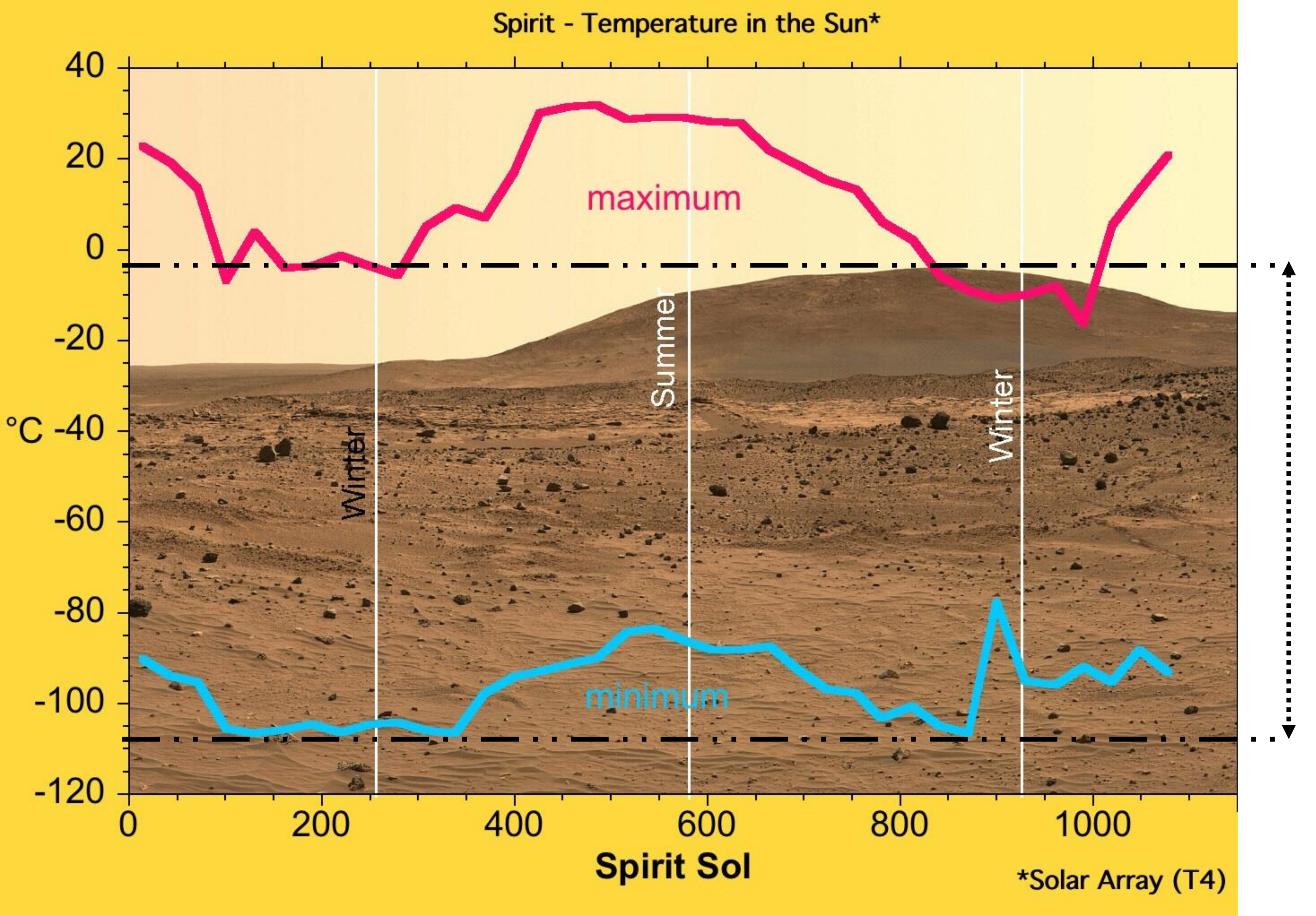
Mechanical properties



CB interacts strongly with **both rubbers** *via* dispersion forces

Silica reacts **more effectively** with **BR** *via* silane links due to the higher double-bond concentration

All day flexible



Daily temperature amplitude can reach 100°C

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

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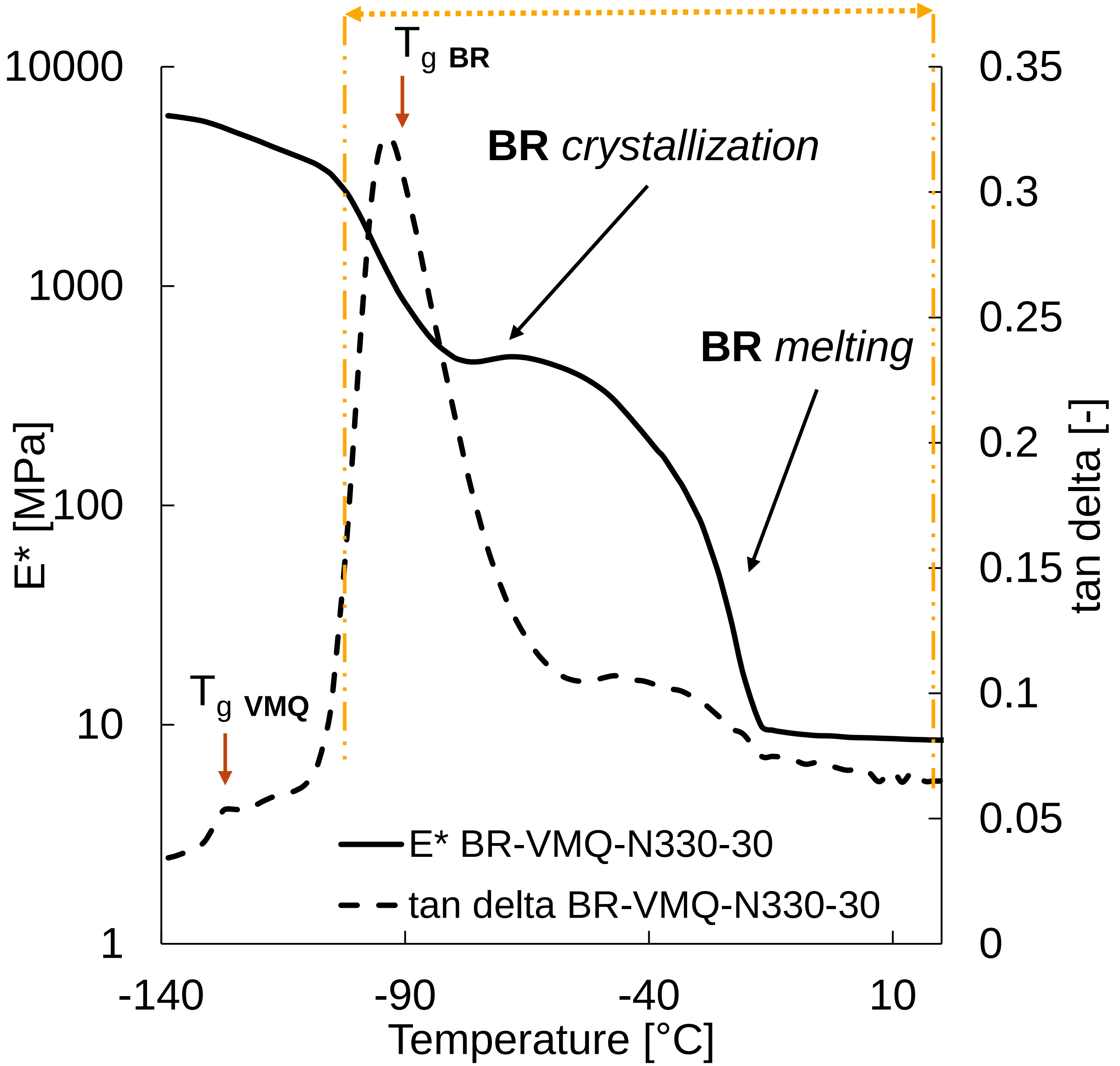
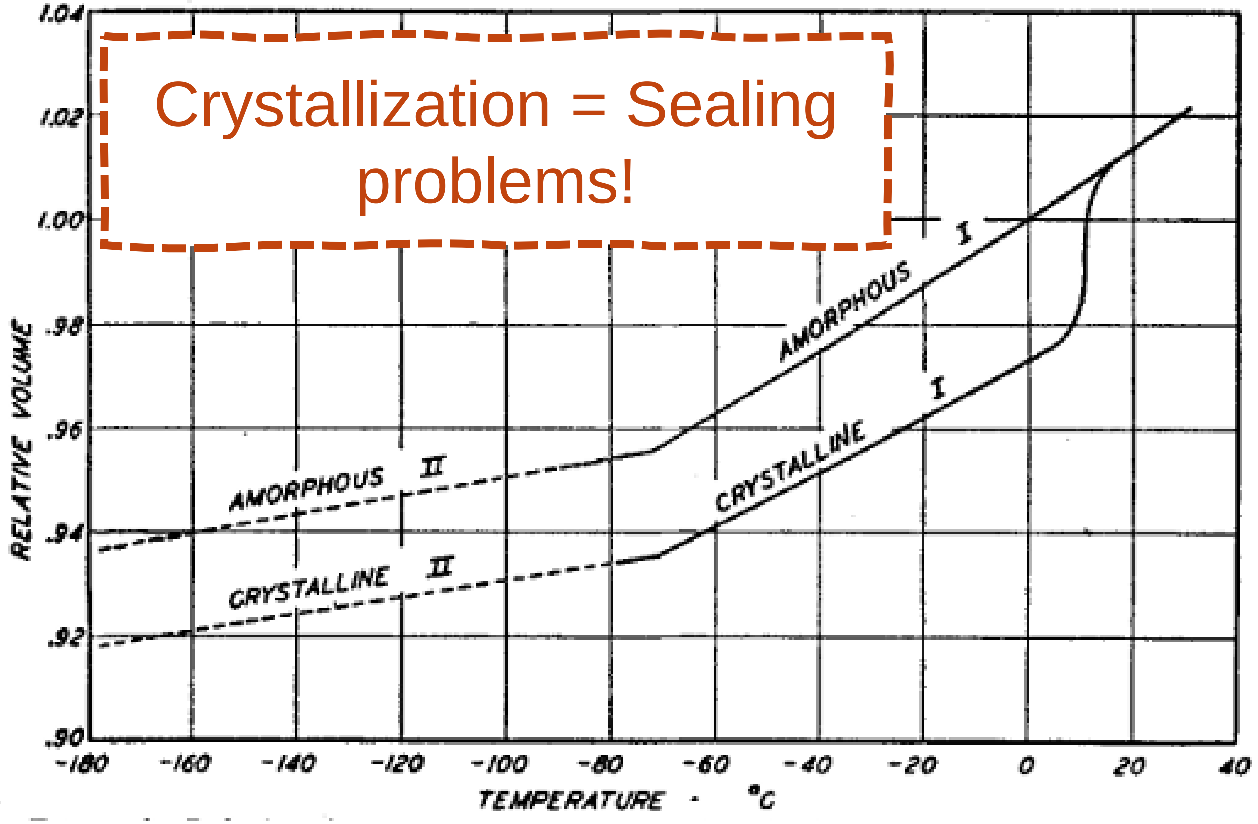
All day flexible

Possible daily temp. amplitude → Daily melting/crystallization of the crystalline phase can pose a threat to sealing performance!



Literature data: Volume change of amorphous and crystalline NR at temperature sweep



Bekkedahl, N. (1934). Forms of rubber as indicated by temperature-volume relationship. J. Res. Nat. Bur. Stand, 13, 411-431.

Finding the right BR

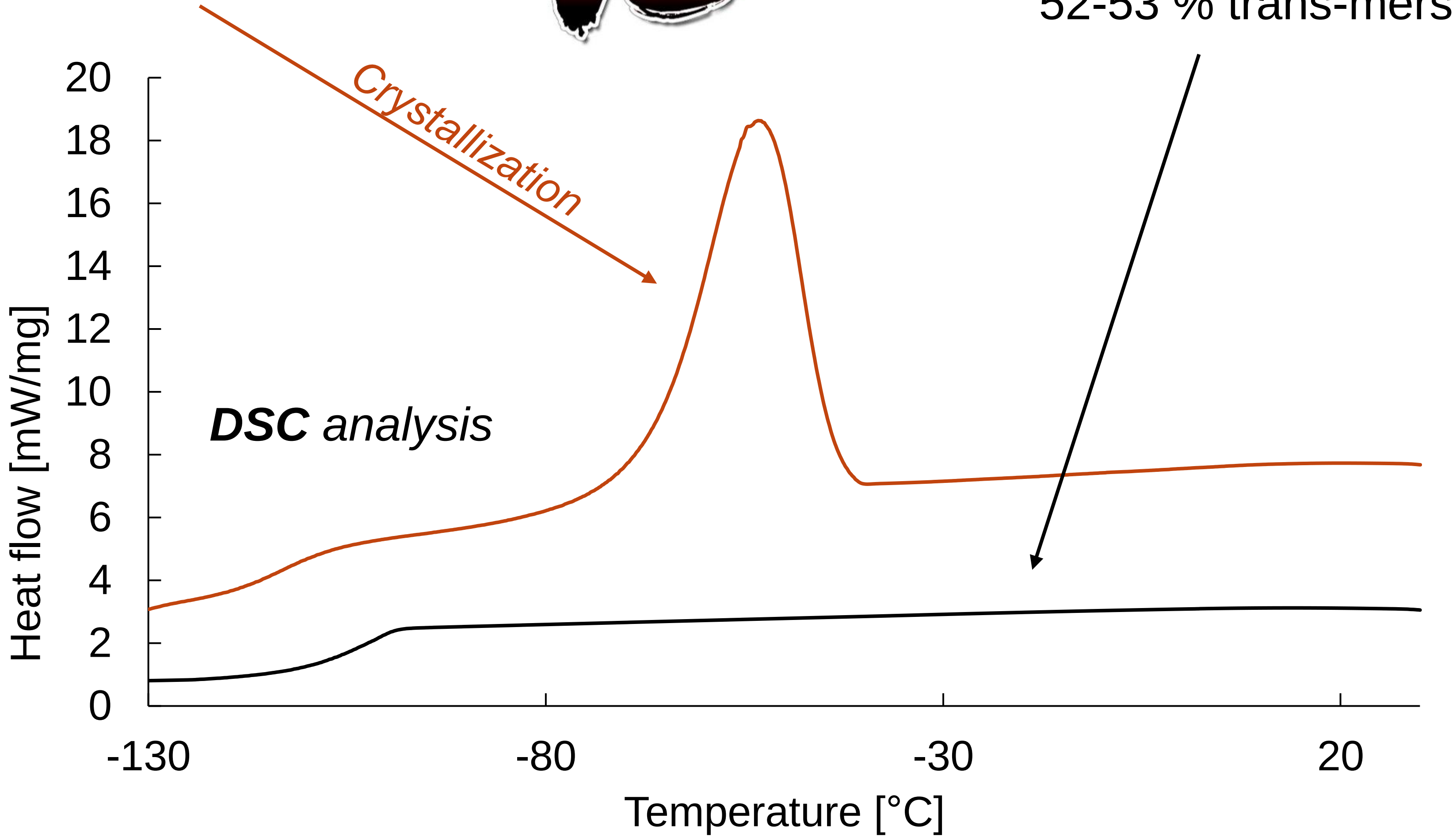
The Battle of BRs

Neodymium-catalyzed BR

- Buna CB24 – >96 % of cis-mers

Lithium-catalyzed BR

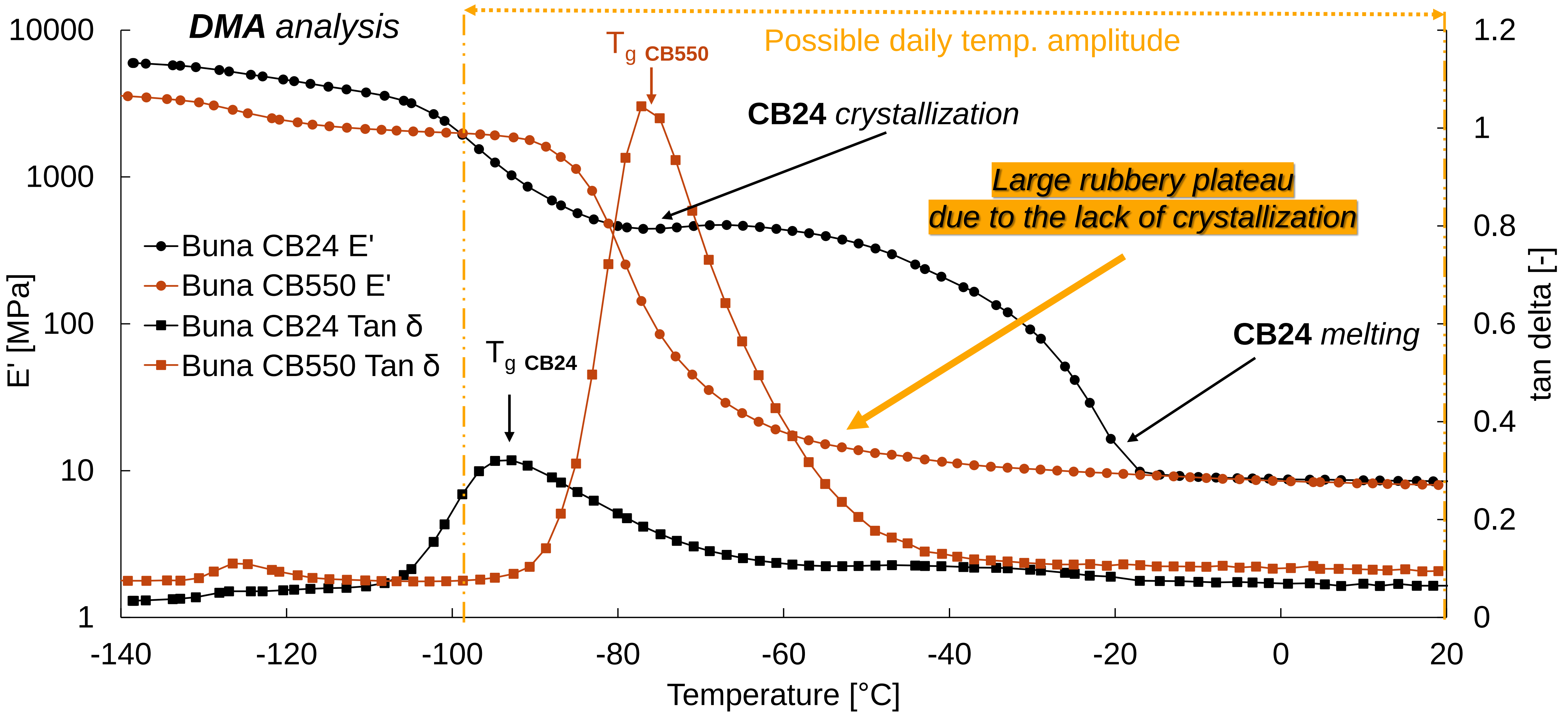
- Buna CB550 – 38 % cis-, 9-10 % vinyl-, 52-53 % trans-mers



Finding the right BR

The Battle of BRs

Vulcanizates filled with 30 phr of N330



The Battle of BRs

- No crystallization
- Larger rubbery plateau

Buna CB550 *Wins!*

https://www.klasgame.com/en/steam-games/209120-street-fighter-x-tekken.html

Future Mars rubber formulation

Vinyl-Methyl Silicone rubber: 20 phr ✓

Amorphous, lithium-catalyzed BR: 80 phr ✓

✓

Reinforcing filler, carbon black: 30 phr ← *Relatively low amount due to a lack of oil in the formulation*

Curatives - sulfur-based system?

Finding oil replacements!

Anti-aging additives, classic antioxidant/antiozonant

Radiation testing

Application of anti-Rads!

UV resistance needs to be improved due to high-energy UV rays on Mars – no ozone layer

Application of anti-UV additives!

Summary

- CB provides better reinforcement to BR/VMQ blends *via* dispersion forces than the silica/silane system due to the scarcity of double bonds in VMQ and possibly worse silica dispersion in comparison to CB

- Crystallizing grades of BR can cause sealing performance problems due to their greater shrinkage with decreasing temperature [1]

- Application of amorphous BR provides a large rubbery plateau of dynamic mechanical properties in a wide range of temperatures, which is promising for potential application on Mars.

1. Bekkedahl, N. (1934). Forms of rubber as indicated by temperature-volume relationship. J. Res. Nat. Bur. Stand, 13, 411-431.

Outlook

- Investigating fillers dispersion in BR/VMQ blends
- Testing and improving radiation and UV resistance of rubber compounds
- Testing non-volatile oil replacements to avoid outgassing
  in the vacuum of space and the low-pressure atmosphere of Mars

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No one will change your flat tire on Mars!

Choose your rubber wisely, with RED 4 MARS!

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Thanks to the industrial partners

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Thank you for your kind attention!

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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; 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/