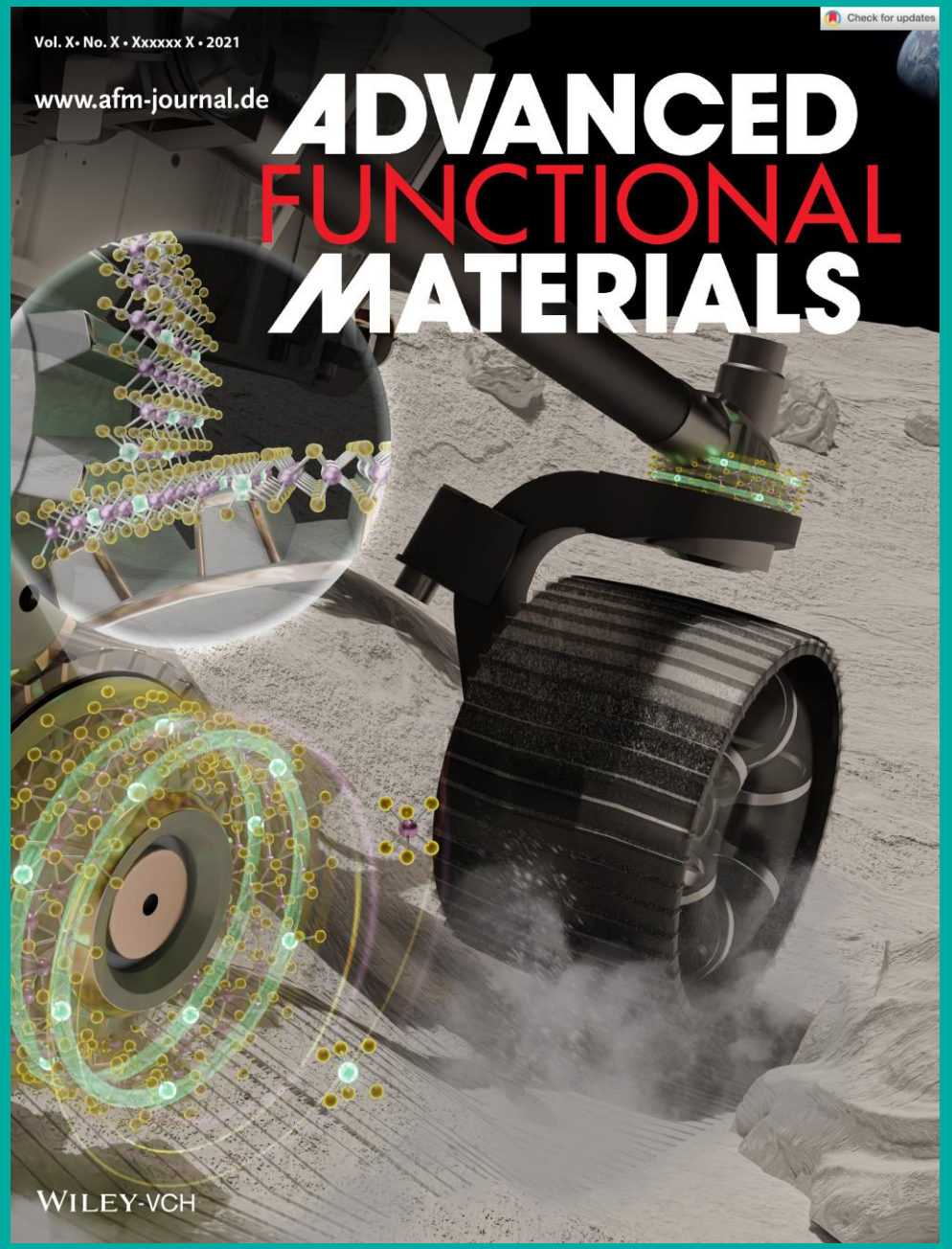
DÉPÔT LUBRIFIANT MOS2+TA POUR APPLICATION SPATIALE - MAINTIEN DE LA LUBRIFICATION LORS DE LA TRANSITION AIR/VIDE

- *Approche de compréhension et design*
- *Performances*

Serles Peter[1,2], Nicholson Eric[3], Tam Jason[3], Barri Nima[2], Chemin Jean-Baptiste[4], Wang Guorui[1], Michel Yann[5], Singh Chandra Veer[3], Choquet Patrick[4], Aurélien Saulot[2], Filleter Tobin[1]

Guillaume COLAS,

CNRS, Institut FEMTO-ST, Besançon



• Design of a new high performance coating for space application

➢ *Space environment ?*

➢ *Space application ?*

3 lives

Earth

Launch

Space

Source: ESA

Source: Ariane Espace

Source: Thalès Alenia Space

Lubrication must be sustained in all those environnements!

Multi-env. Tribology

Performances on Ground = Space is critical

Different specific characteristics

- **Mechanics**
- **Physico-chemistry**
- **Temperatures**

Ground tests = up to 30% of the total mechanism life

• Design of a new high performance coating for space application

➢*Space environment ?*

➢*Space application ?*

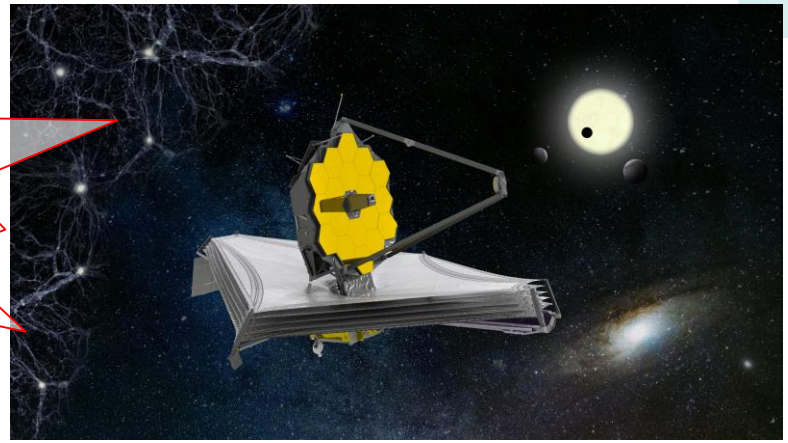
Lubrication must be sustained in all those environnements!

Multi-env. Tribology

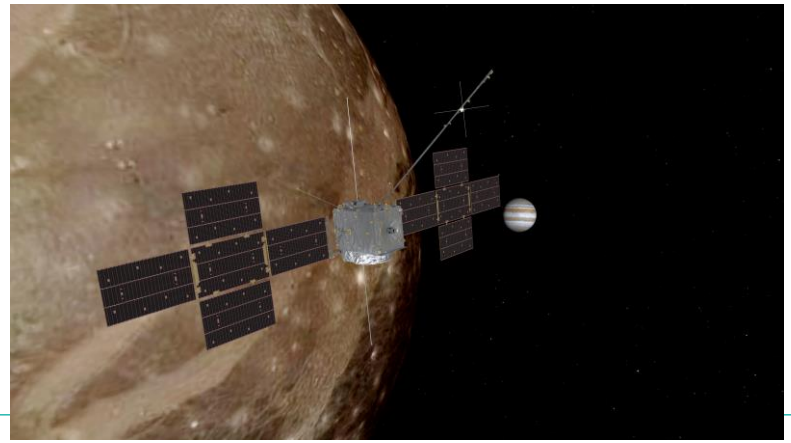
Performances on Ground = Space is critical

Recent issues

2022 - JWST
High friction in MIRI instrument



2023 - JUICE
Boom Antenna deployment (pin stuck)



• Design of a new high performance coating for space application

➢ *Literature full of contradictions?*

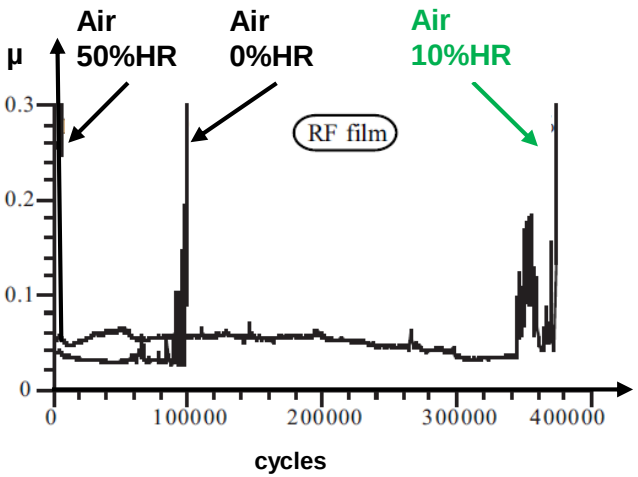
Common thoughts MoS_2

Air
Humidity is detrimental

Vacuum
Internal contamination detrimental

Dry N2 at Patmo
mimics UHV

not always



MATSUMOTO K, SUZUKI M ESMATS 1999

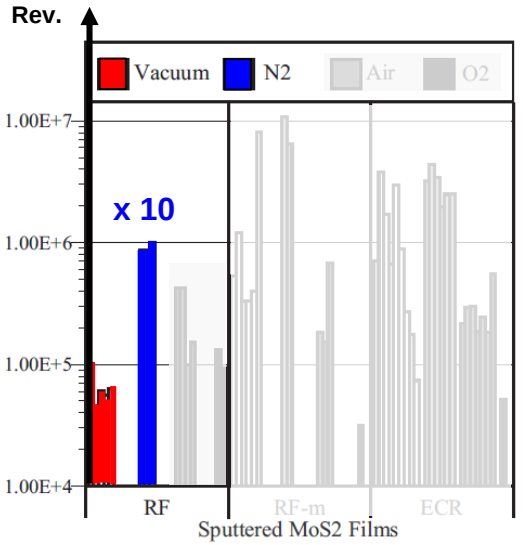
Disagreements

It is,
Donnet, 1996

Not necessarily
Buck 1983 & 1987, Finch 1950

Depends on vacuum level
Colas 2013 & 2015

does not mimic



MATSUMOTO K, SUZUKI M ESMATS 1999

• Design of a new high performance coating for space application

➢ *Literature full of contradictions?*

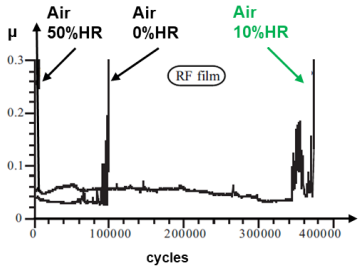
Common thoughts MoS_2

Air Humidity is detrimental

Vacuum Internal contamination detrimental

Dry N2 at Patmo mimics UHV

not always



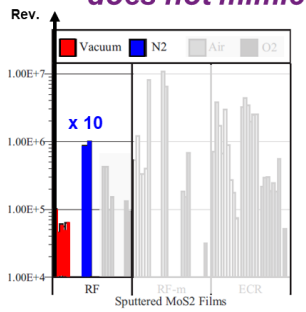
Disagreements

It is,
Donnet, 1996

Not necessarily
Buck 1983 & 1987, Finch 1950

Depends on vacuum level
Colas 2013 & 2015

does not mimic

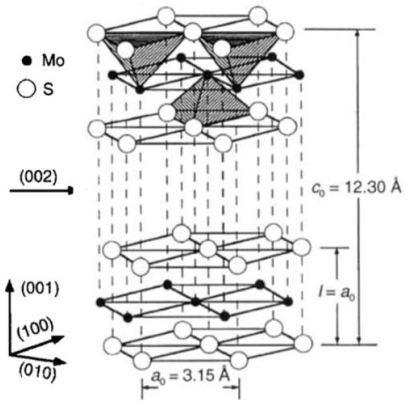


MATSUMOTO K, SUZUKI M ESMATS 1999

Friction coefficient and wear lives <u>alone</u> do not allow understanding nor predicting a tribological behaviour

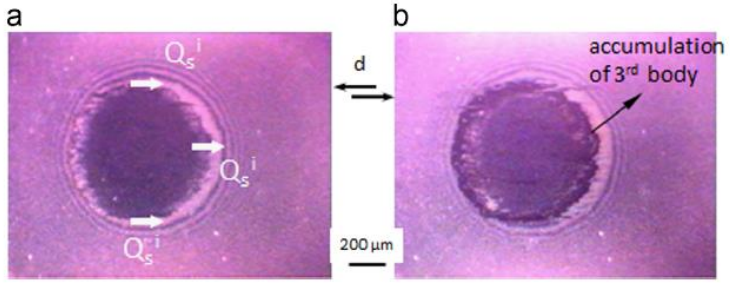
➢ *Any agreements ?*

Yes ! Lubrication by shear, sacrificial damage of coating surface, circulation of 3rd body materials



MoS_2 Trigonal Prismatic Structure [1]

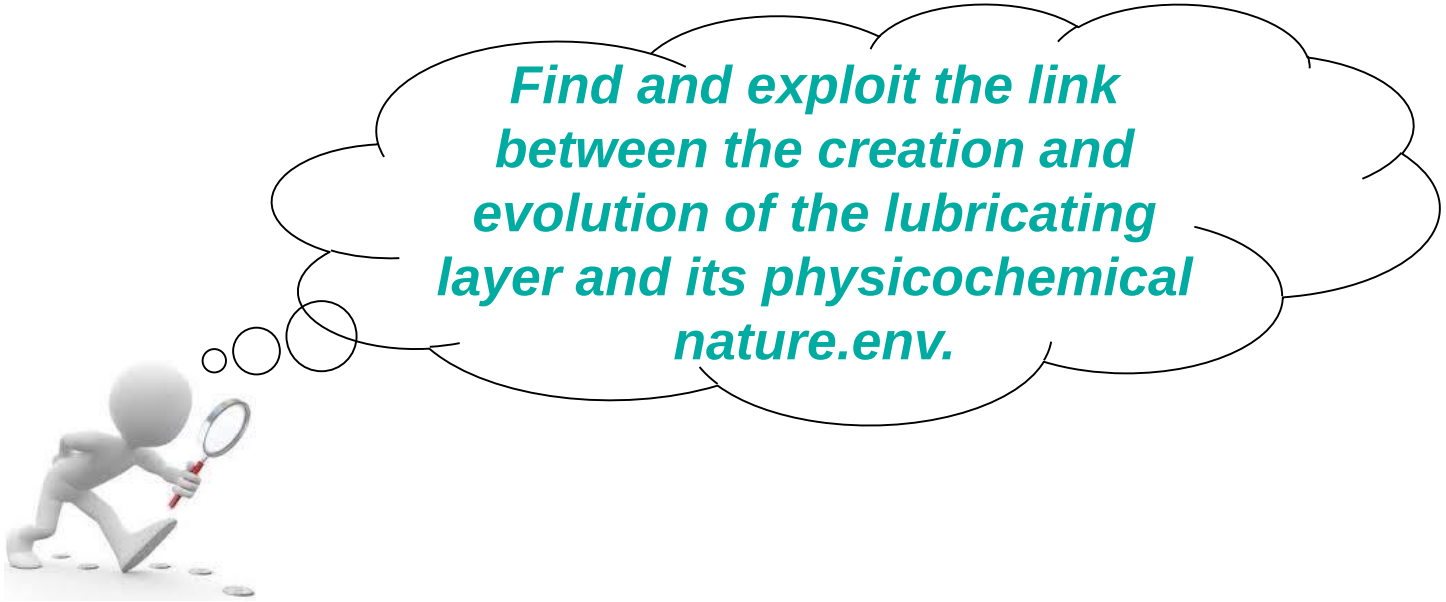
[1] Savan, A. et al., *Lubr. Sci.* 2000.



Descartes, et al, 2015.

Singer E, et al, 1990 ; Wahl, K, et al, 2000 ; etc….

• Design of a new high performance coating for space application



In-situ gas analysis

Friction force

Video

Air

Vide

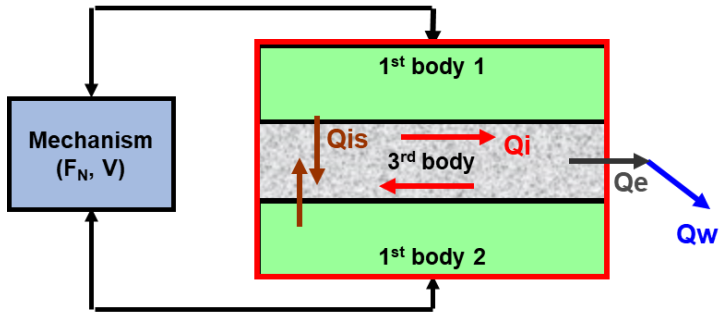
N_2

V

F

MoS2 1µm

➢ *Contact life reconstruction*



3rd body flows

Solid	*Gaseous*
Qis	gQis
Qi	gQi
Qw	gQw
…	…

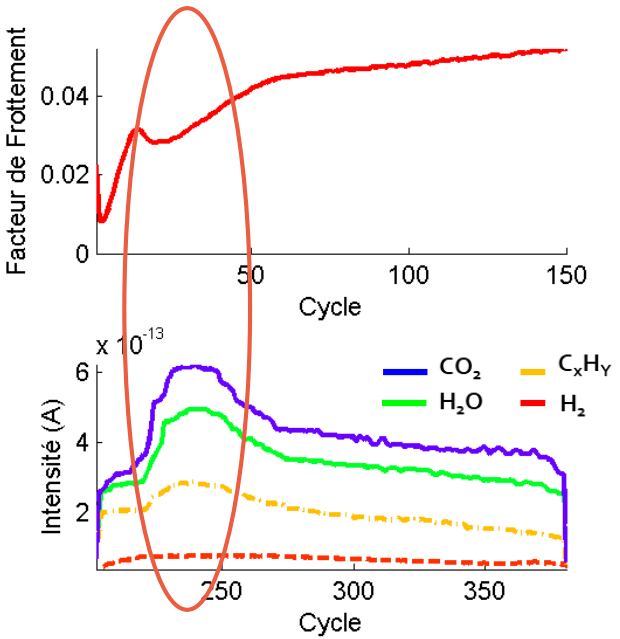
SEM

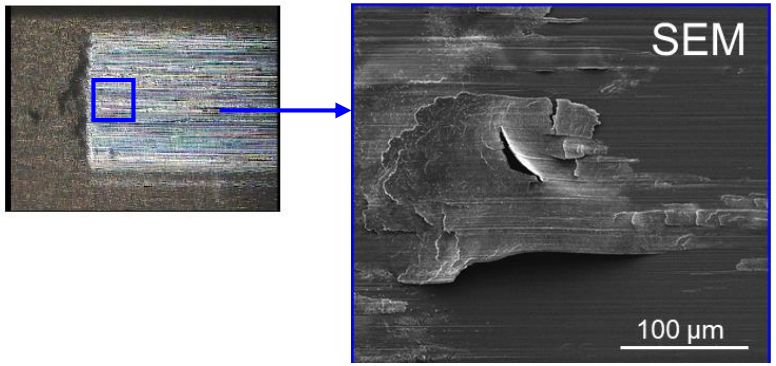
ToF-SIMS

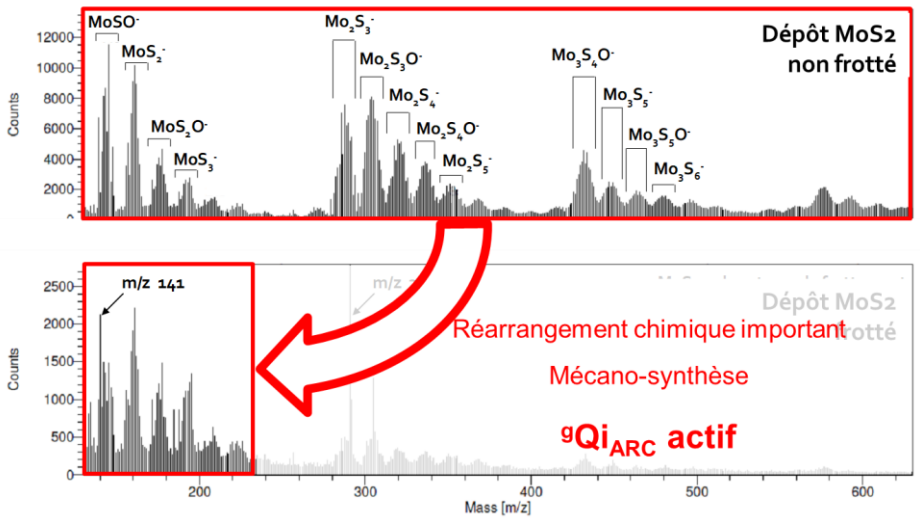
EDX

• Design of a new high performance coating for space application

Sous UHV

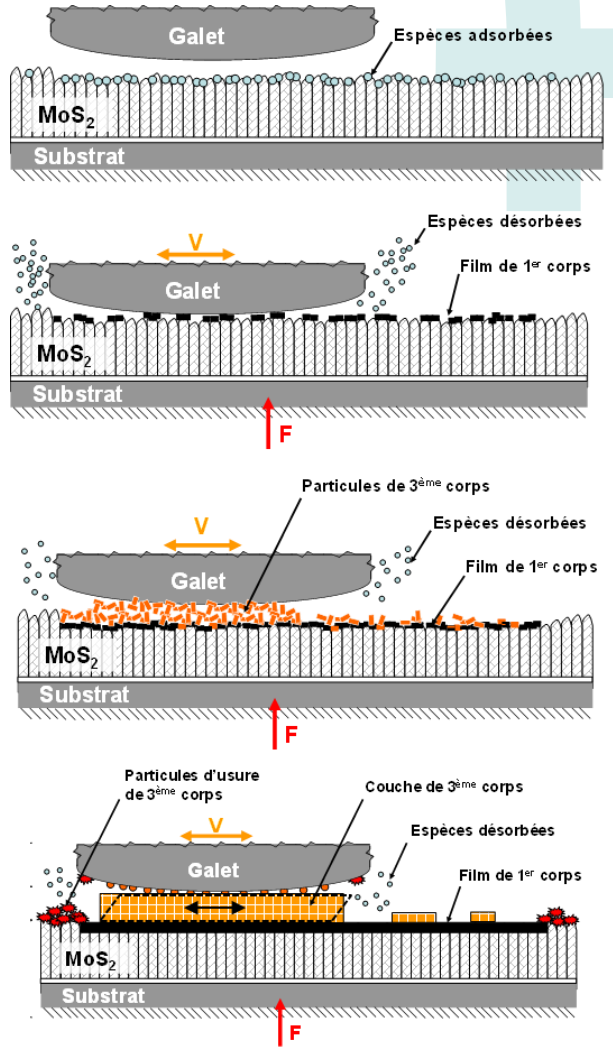






ToF-SIMS

Top surface chemistry

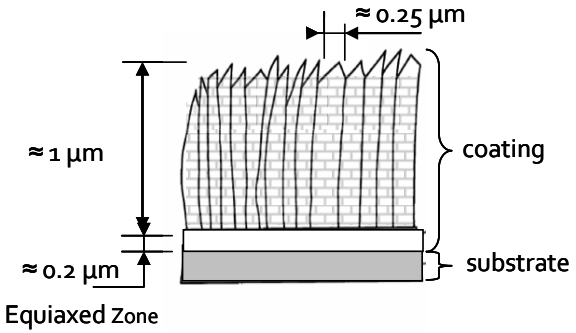


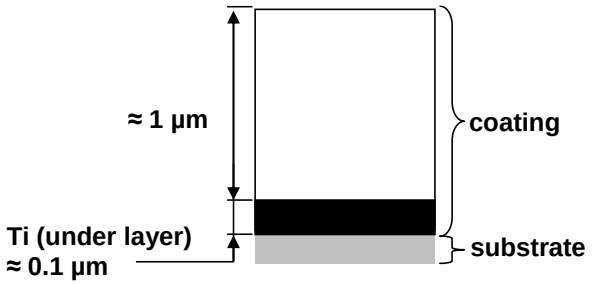
• Design of a new high performance coating for space application

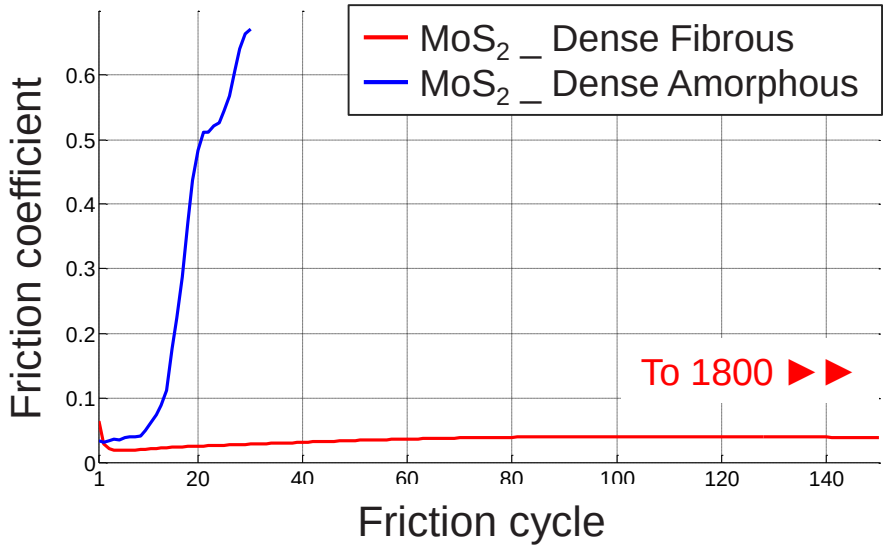
➢ *The denser the better?*

➢ *Two MoS2 coatings _ Friction in UHV*

Dense Fibrous	Dense amorphous
Amorphous and nanocrystaline	Fully nanocrystalline





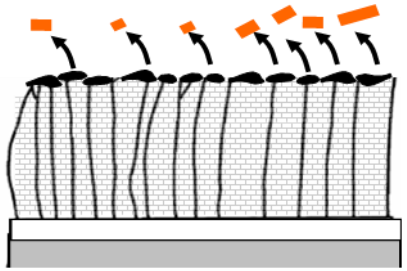


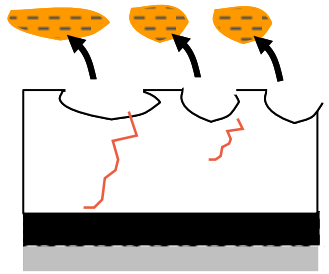
• Design of a new high performance coating for space application

➢ *The denser the better?*

➢ *Two MoS2 coatings _ Friction in UHV*

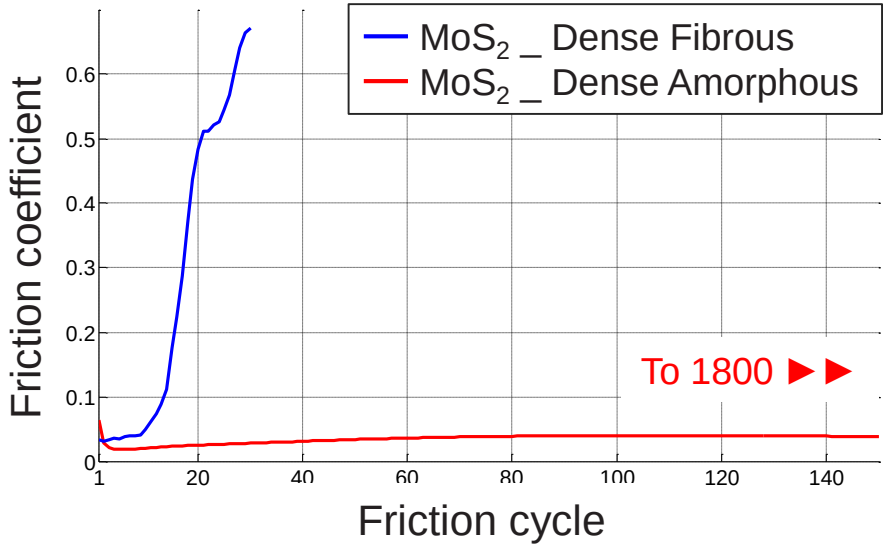
Dense Fibrous	Dense amorphous
Amorphous and nanocrysttline	Fully nanocrystalline





Sacrificial surface damage, small particle

Crack propagation, large particle, coating depletion

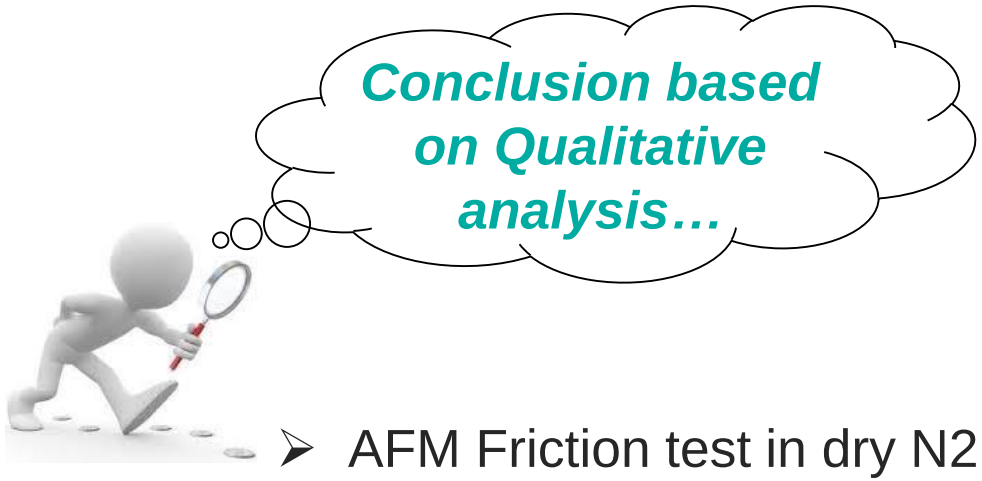


Efficient MoS2 lubrication in vacuum

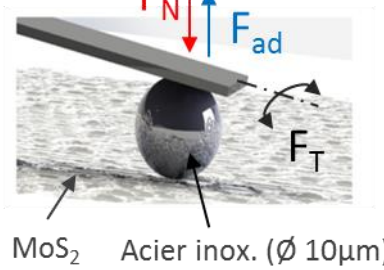
if particles small enough to stay trapped inside the contact

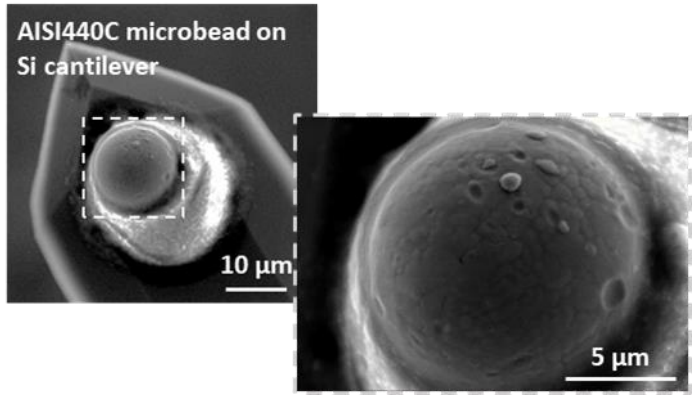
➢ Coating with relevant morphology

• Design of a new high performance coating for space application

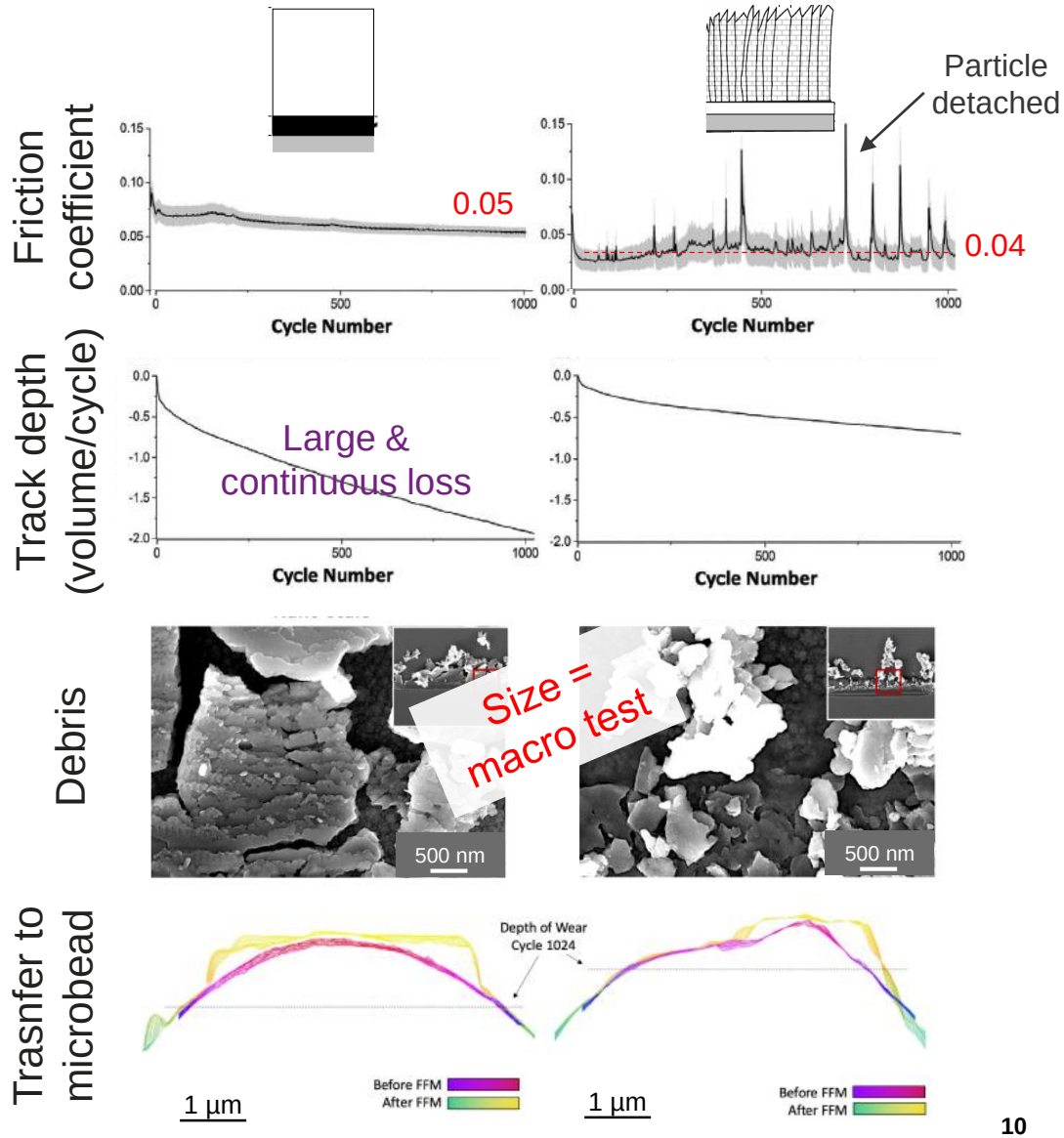


➢ AFM Friction test in dry N2

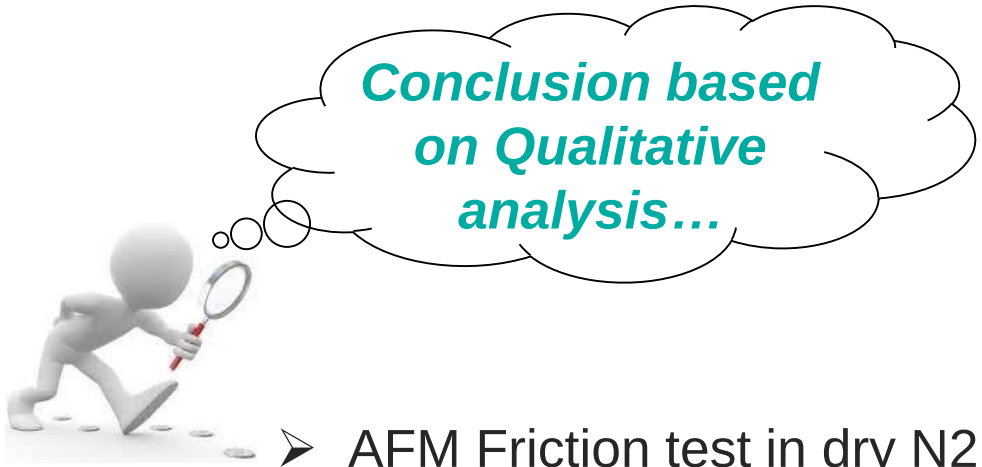




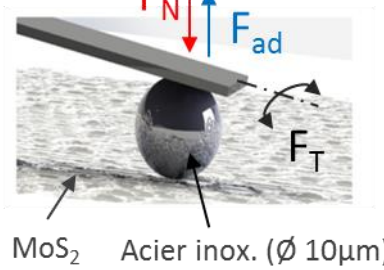
1 GPa (Fuller & Tabor)
Reciprocating, 60µm track length
Vs = 15µm/s ; Nb cycle = 1000

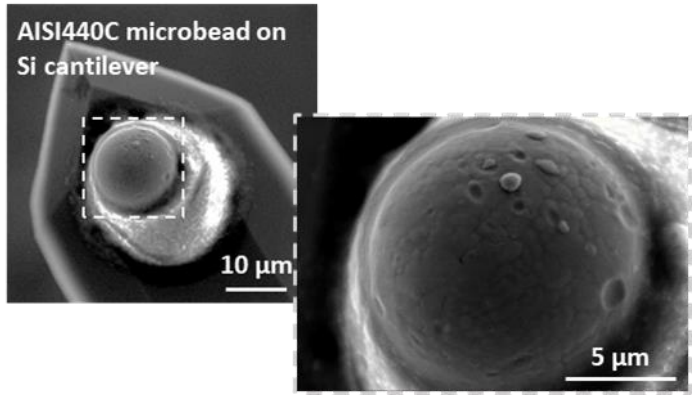


• Design of a new high performance coating for space application

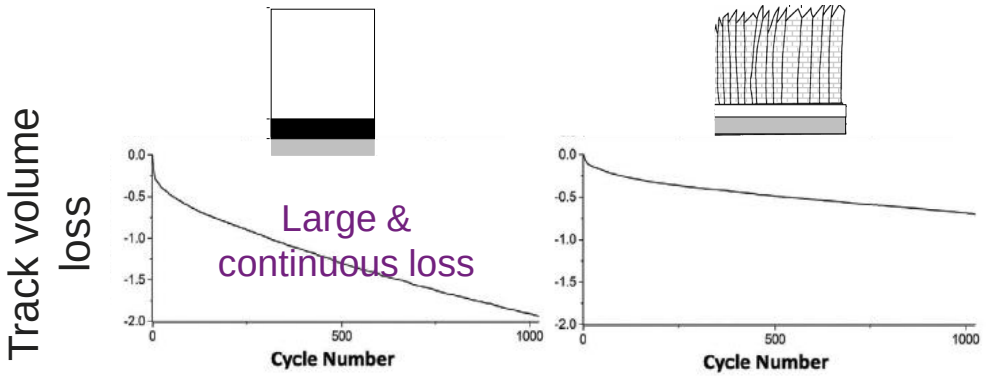


➢ AFM Friction test in dry N2

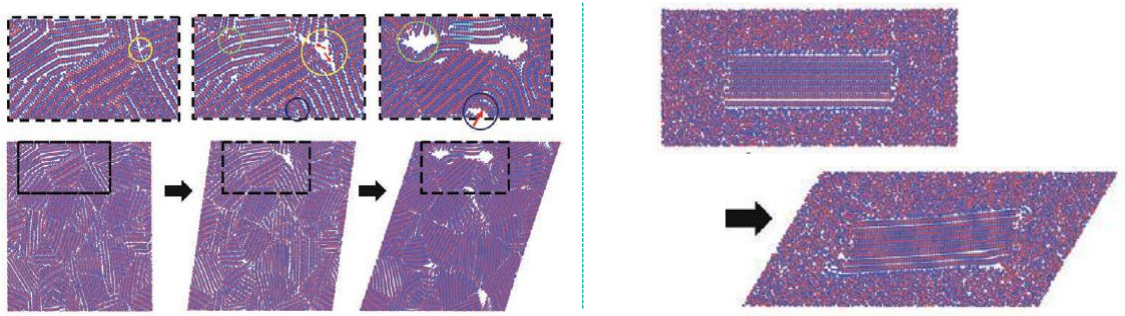




1 GPa (Fuller & Tabor)
Reciprocating, 60µm track length
Vs = 15µm/s ; Nb cycle = 1000



➢ Molecular dynamics



↳ 21% lower shear stress, ultimate shear @ 20% lower strain

↳ Cracks, continuous particle detchmt

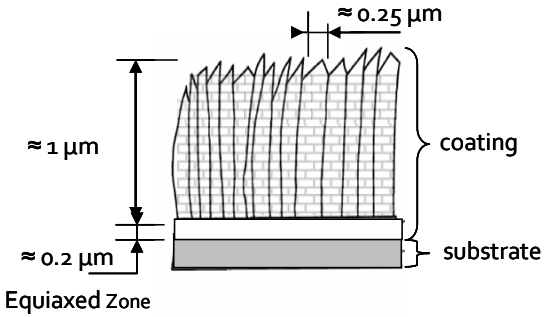
➢ Coating with relevant morphology, semi-crystalline

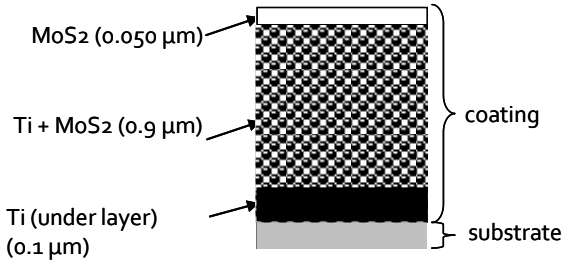
• Design of a new high performance coating for space application

➢ *How to make it resist ground to space transition ?*

➢ *Two Antagonists MoS2 based coatings*

Dense Fibrous	Dense amorphous
Amorphous and nanocrysttline	Fully nanocrystalline





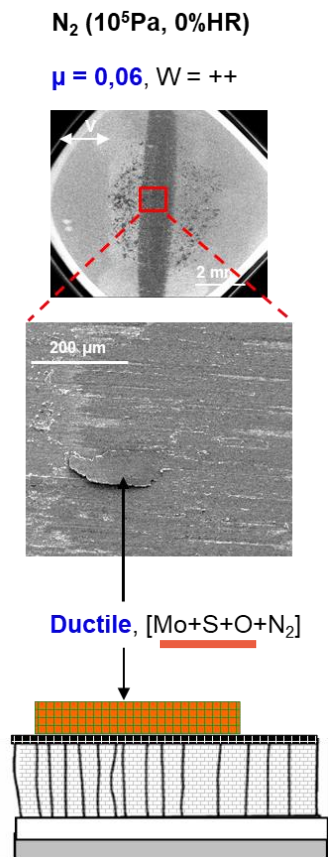
MoS_2

Lub. In Vacuum, dry N2

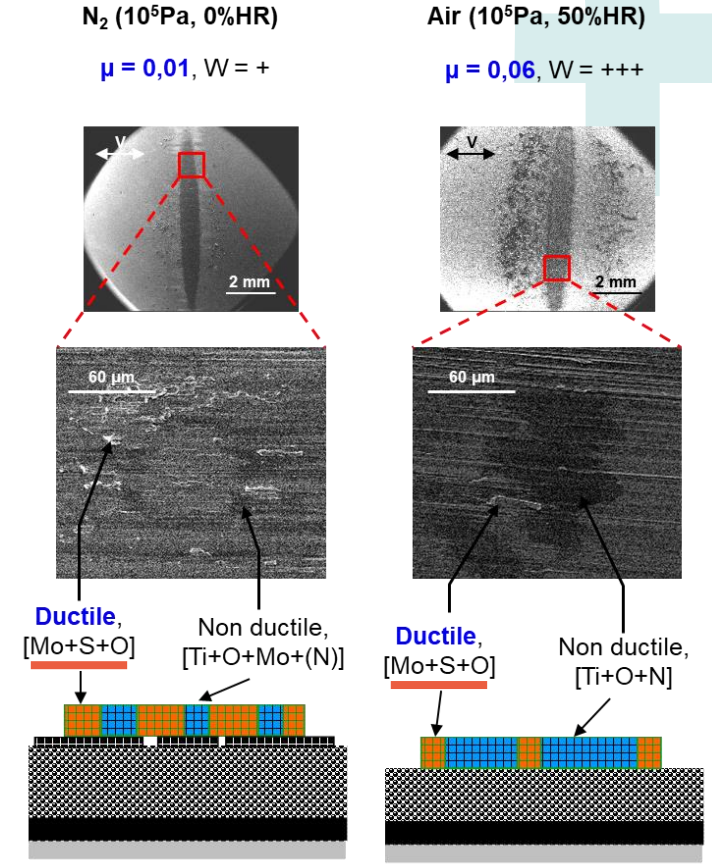
MoS_2 + 10%Ti

Lub. In Air and dry N2

MoS_2



MoS_2 + 10%Ti



➢ *N_2 and H_2O Physisorb / chemisorb*

➢ *MoS_xO_y presence => like MoS_2 in UHV*

• Design of a new high performance coating for space application

➢ *To summarize, coating sustaining ground => space working environment ?*

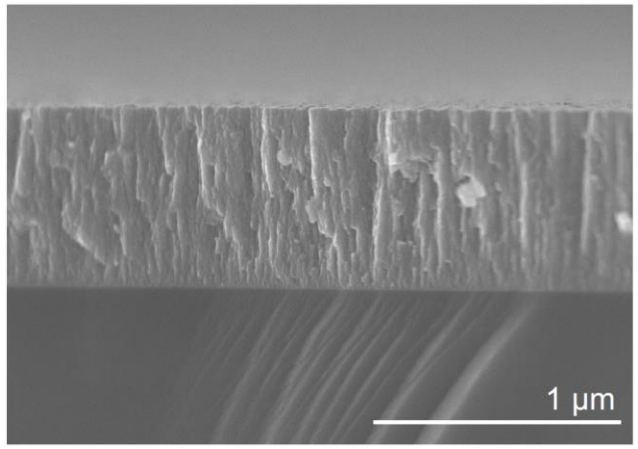
- ➢ Coating with relevant morphology and partially crystalline
  - ➢ Localize cracks at coating surface
    - ➢ Local detachment of particle small enough to be trapped
      - ➢ Agglomeration into ductile 3rd body layer

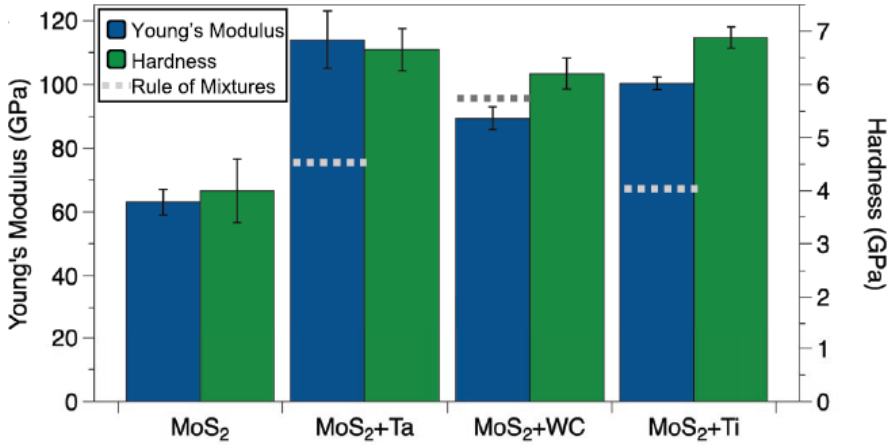
- ➢ Addition element to protect MoS2 and Lubricate
  - ➢ Gaseous in nature => e.g. internal contaminants of MoS2
    - ➢ MoSxOy, not perfect but lubricious capabilities

  - ➢ Solid => getter effect to protect MoS2 against further oxidation
    - ➢ Selective chemisorption
    - ➢ But must also be lubricious in vacuum environments

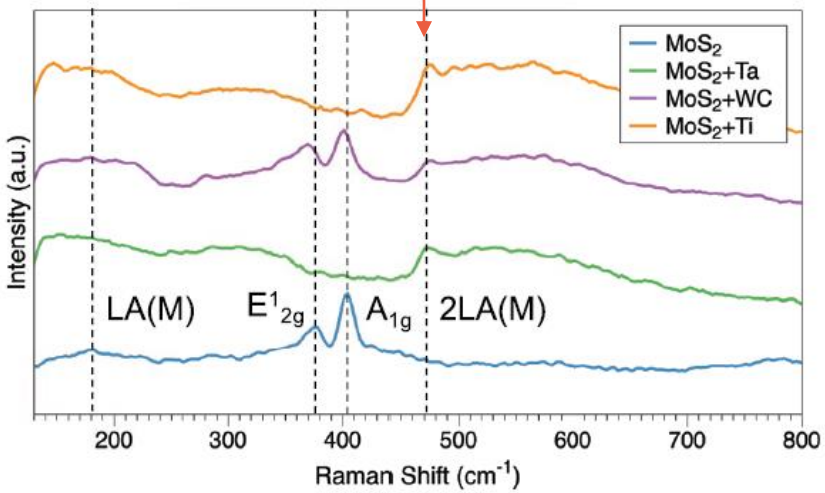
• Our new high performance coating for space application

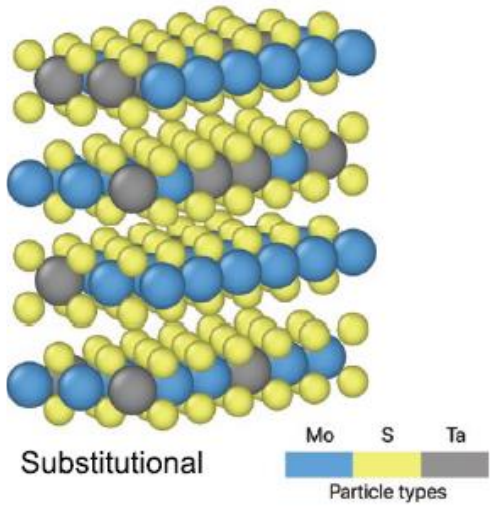
- *MoS2 + 10%Ta + O*
- *PVD Deposition*
- *Dense fibrous*
- *Hard*
- *Crystalline ?*





Desorder peak





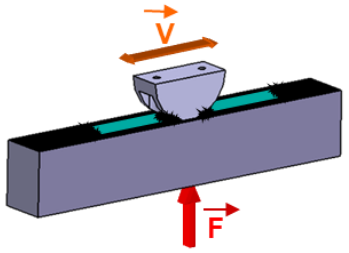
Mo substitution by Ta

- *<u>XPS shows</u>*
  - *MoS_2 *; TaS_2 **
  - *Ta_2O_5 *; peu de MoO_2*
  - *MoS_xO_y *; TaS_xO_y ***
  - *Mo-Ta-S-O most likely*

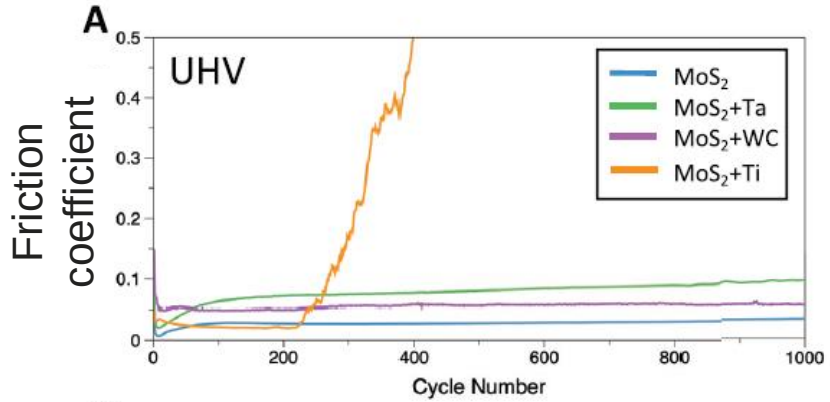
** Lubricious in vacuum or air ;*
*** most likely lubricious*

• Our new high performance coating for space application

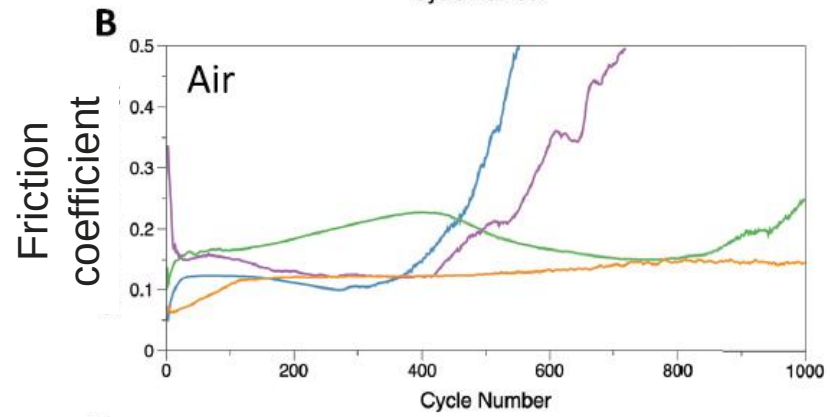
➢ *Works?*



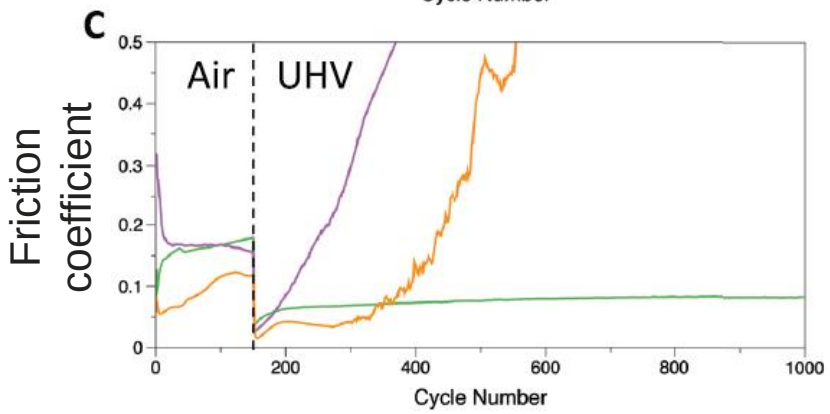
Coating 1µm
1 GPa
10 mm/s



➡ Below 0.1 => Success



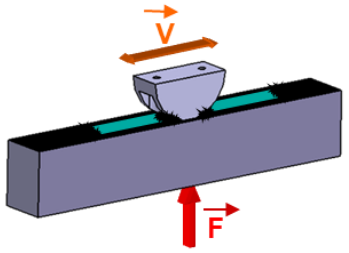
➡ in 0.15 – 0.2 range
No lubrication faillure => 2/3 Success
Better than MoS2



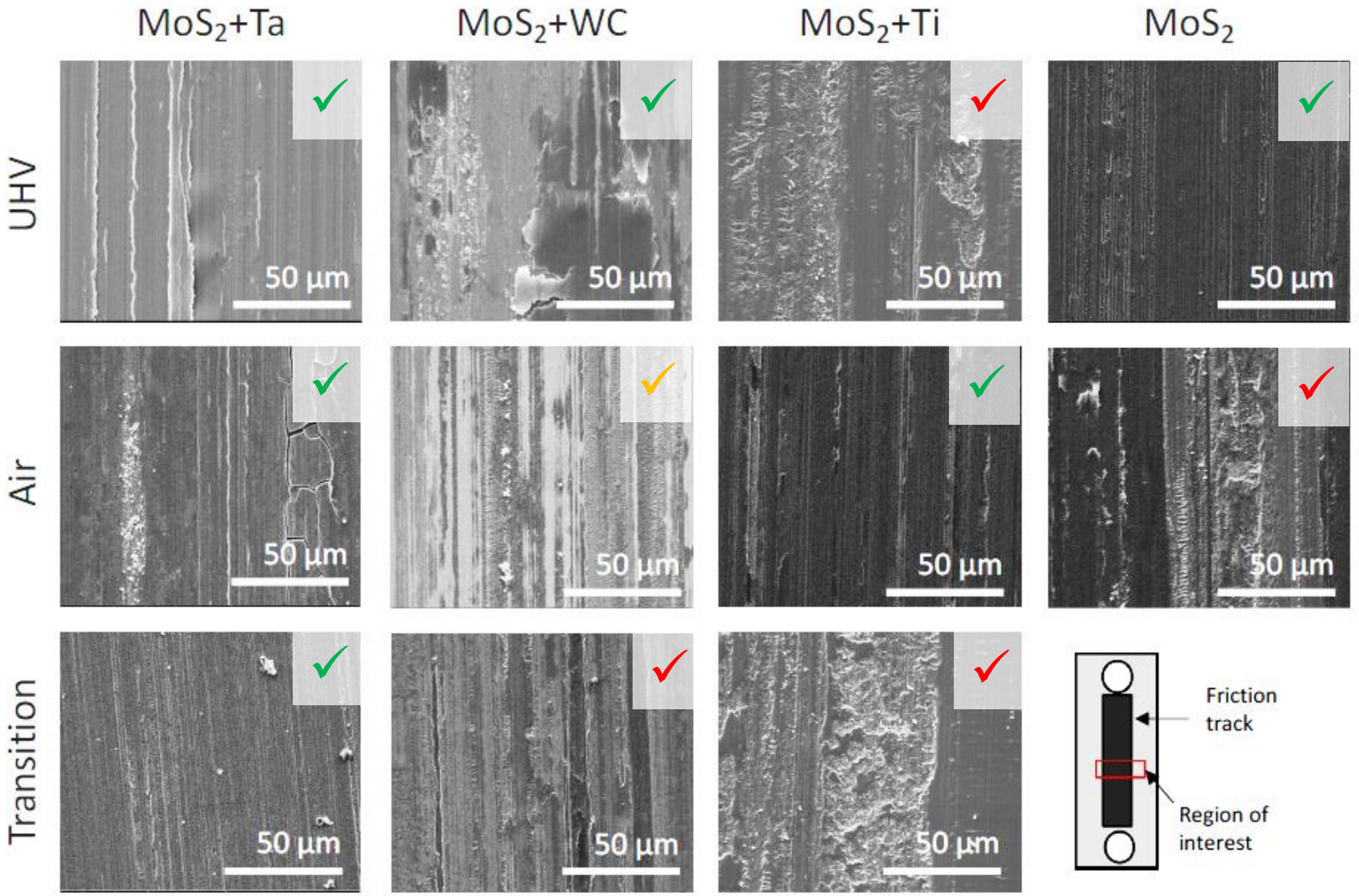
➡ Below 0.1 in UHV
Definitely the best => Success
MoS_2 failed at 150 cycles

- **Our new high performance coating for space application**

➢ *Works?*



Coating 1µm
1 GPa
10 mm/s

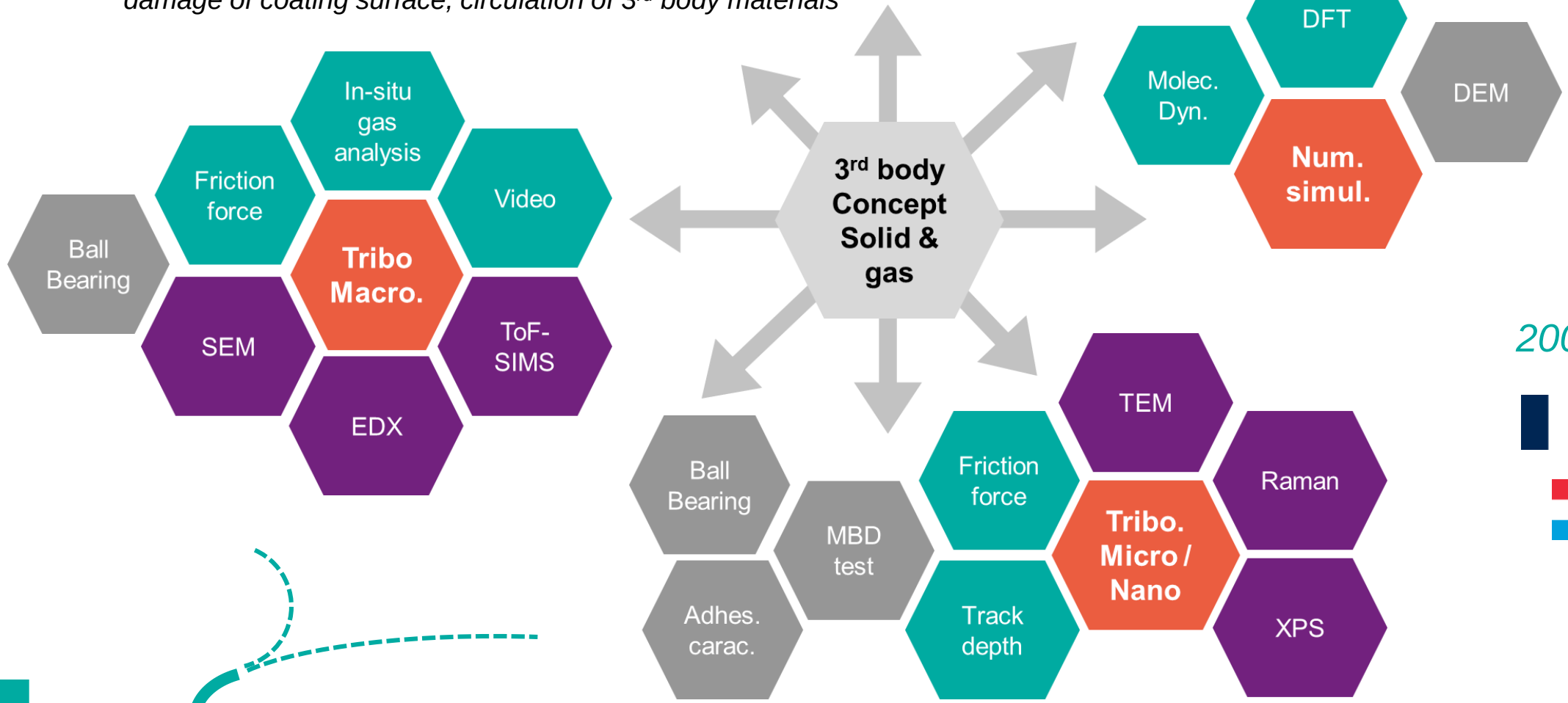


➢ Success => Damaged and wear resistance, Lubriciousness

• Conclusion

➢ *Design coating for space lubrication*

➢ *Literatures agrees only on : Lubrication by shear, sacrificial damage of coating surface, circulation of 3rd body materials*



2009 to 2022

Successful design of new coating

• Our new high performance coating for space application

➢ ***2023 => 2026***

➢ *TRL 3 => TRL7*

➢*Validation to pass to pre-certfication / prequalification stage of the coating for space flight*

➢*Pure sliding, rolling+sliding*

➢*Different environment*

➢*Ball bearing level test*

➢ *3 space agencies*

cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

LSA LUXEMBOURG SPACE AGENCY

➢ *3 laboratories*

femto-st SCIENCES & TECHNOLOGIES

LaMCoS UMR 5259

LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY | LIST

➢ *1 industrial*

Vacuum tribometer @FEMTO

Thanks for your attention

Acknowledgements:

Aurélien Saulot
Yves Berthier
Claude Godeau
Didier Leonard
David Philippon
Mathieu Renouf
Yannick Baudassé
Fabrice Champandard
Alain Mistral
….

Tobin Filleter
Peter Serles
Simo Pajovic
Chandra Veer Singh
Jason Tam
Eric Nicholson
Andrew Gibson
Peter Cameron
Alexander Beaton
……

Jean-Baptiste Chemin
Patrick Choquet
Thierry Girot

Our papers related to this presentation

[1] G. Colas, et al, Tribol. Int. 65 (2013) 177–189
[2] G. Colas, et al. Wear. 305 (2013) 192–204
[3] G. Colas, et al, Wear. 330–331 (2015) 448–460
[4] G. Colas, et al. Thin Solid Films. 588 (2015) 67–77
[5] S. Pajovic, et al, Adv. Eng. Mater. 1700423 (2017)
[6] G. Colas, et al, ACS Appl. Mater. Interfaces. 10 (2018) 20106–20119
[7] G. Colas, et al, J. Mech. Phys. Solids. 128 (2019) 151–161
[8] P. Serles, et al, Adv. Mater. Interfaces. 7 (2020)
[9] P. Serles, et al, Adv. Funct. Mater. 2110429 (2022)

1 patent application (2021)