MEDSI 2004
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TRIBOLOGY IN EXTREME ENVIRONMENT: STATE OF THE ART AN SOME SOLUTIONS FOR SOLID LUBRICATION IN UHV

M. Belin, J. Fontaine, Th Lemogne

Laboratoire LTDS, UMR CNRS 5513, Ecole Centrale de Lyon
36 rue Gay de Collongue, 69134 Ecully, France
michel.belin@ec-lyon.fr

MEDSI 2004
Tuesday, May 25

Michel BELIN

MEDSI 2004
ESRF, Grenoble
May 24-27, 2004

Tribology in extreme environment:
state of the art and some solutions for solid lubrication in UHV

Michel BELIN, Julien FONTAINE and Thierry Le MOGNE
michel.belin@ec-lyon.fr

LTDS - Laboratoire de Tribologie et Dynamique des Systèmes
Ecole Centrale de Lyon - UMR 5513

Outline

1. Introduction
2. Background on tribology
3. Vacuum tribology
4. Experimental simulation
5. C-based coatings
6. Conclusions & perspectives

1. Introduction

- **In SR: complex systems in extreme envir.**
  - vacuum
  - thermal gradients

- **Moving parts**
  - positioning
  - dynamic motion

- **High precision**
  - mehanical components
  - electronics, magnets, high loads

Objective of this presentation:

- Reduce the gap between space technol. and SR word
- Present a group/a facility, show some results

2. Background on tribology

- **Interaction between solids**
  - sliding: accomodation of speed difference
  - load carrying
  - friction, wear, interface, lubrication...

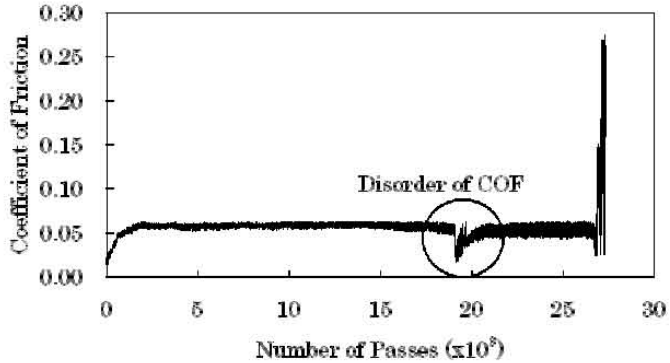
- **Friction**
  - level of friction (f= Ft / Fn)

    energy loss

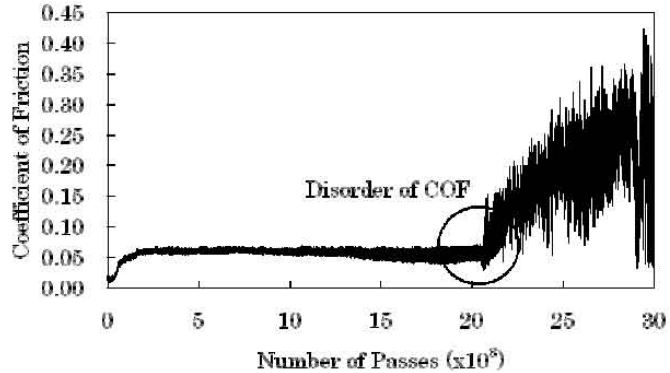
friction value f	10^{-3}	10^{-2}	10^{-1}	1	10
EHD lubrication		0.02	0.3		
HD lubrication	0.003		0.2		
dry lubrication		0.05	0.8		
vacuum friction	0.002				5

- friction stability
  noise (stick-slip)

- f(N), evolution with cumulated sliding distance



(a) Storage Period: 12 months



(b) Storage Period: 18 months

sputtered MoS_2 in vacuum
storage duration effect in moist env.

IWAKI M. *et al.* (2004)

- **Wear**
  - weight loss
  - lifetime ➔ malfunction
  - coupling to friction
  - wear possible emission ➔ debris, vapors

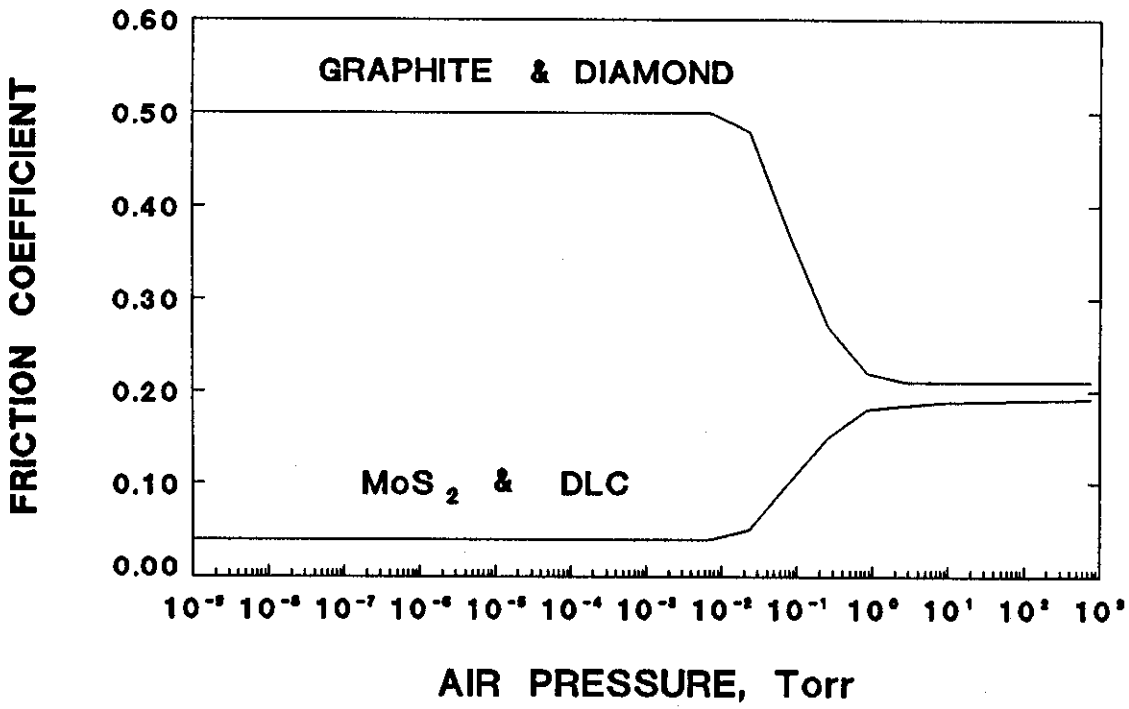
    ➔ major breakdown of mechanism

    ➔ environment pollution

The tribological behaviour is not intrinsic to a material, or to a material pair

■ Dependence vs environment

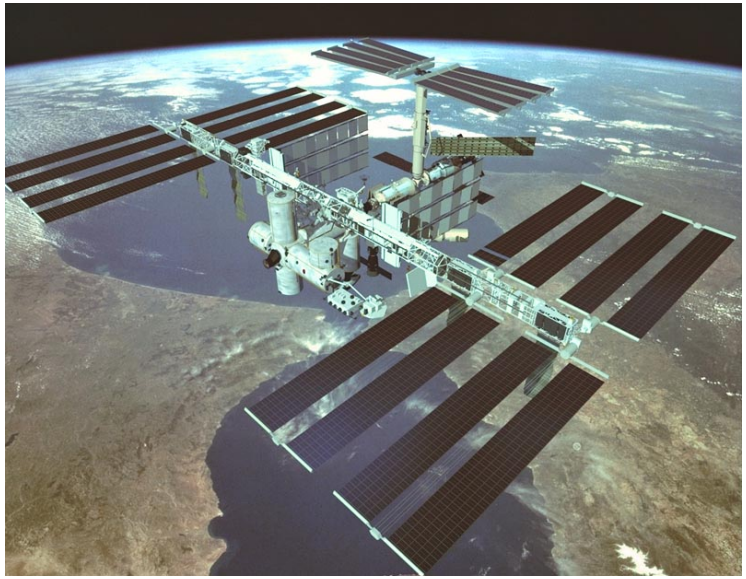
BUCKLEY D.H. (1991)



- ▶ strong dependence vs environment
- ▶ no clear link with structure & chemical composition

3. Vacuum tribology

ISS station



- **Space tribology**
  - reliability
  - life time
  - precision
  - performance stability
  - debris, O g conditions, pollution of instruments

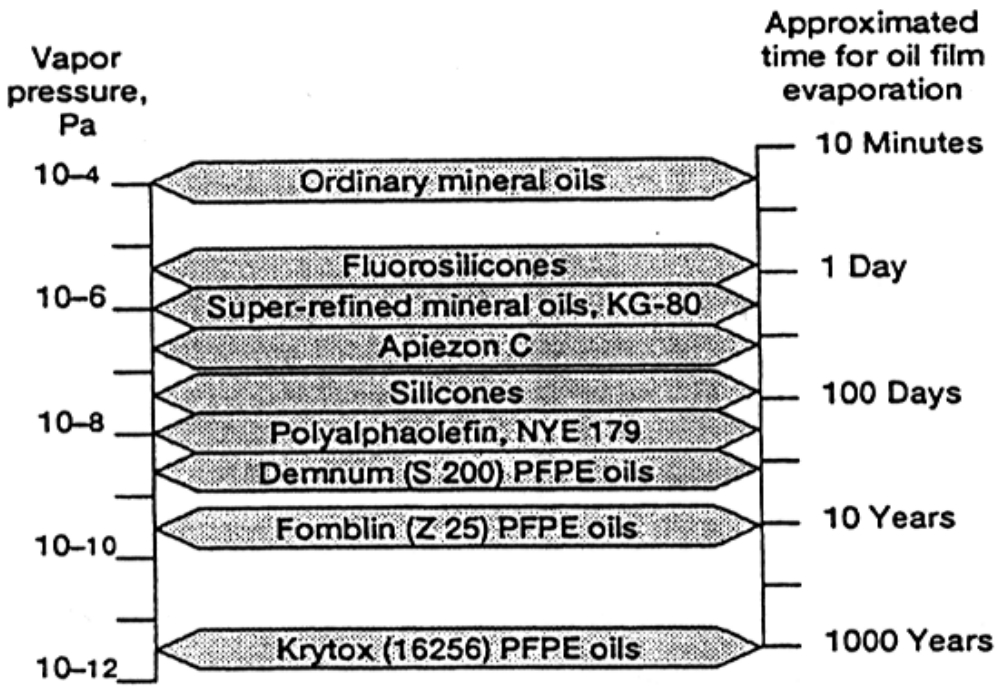
- **SR instrumentation**

Comparing space / SR requirements

	space	SR
vacuum (hPa)	**$10^{+3} \rightarrow 10^{-8}$**	**$10^{-9} \rightarrow 10^{-11}$**
lifetime	critical (15 years)	high
radiation, particles	AO, $h\nu(\lambda)$, e^- , protons	$h\nu(\lambda)$, e^-
thermal	150 - 400 °K	? 1 - 400 °K
vibration	few g (launching)	< 1 g
microgravity	x	/

Specific solutions for space applications

1. Liquid lubricants



- **minimizing evaporation in vacuum**

2. Solid lubricants for space

SINGER I.L. (1991)

- **Soft metals**
  - **Au, Ag, In, Sn**

- **Chalcogenides**
  - **MoS_2, WS_2, Sb_2Se_3...**

- **Polymers**
  - **PTFE, polyimide**

- **Technological issues**
  - **sputtering** **thin coatings (0.05 to 1 micron)**
  - **ion plating**
  - **painting / binders**

3. Some benefits and limitations

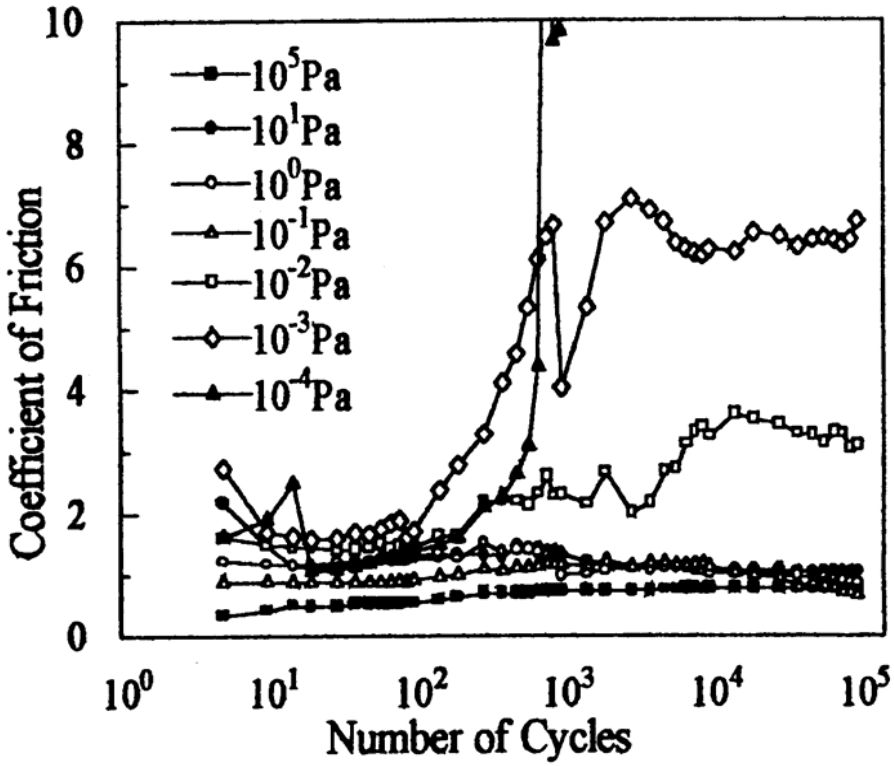
lubricant	+	--
liquid	- long lifetime - low friction - heat evacuation	- dep. with temperature - migration
solid	- lo dependance with temp - possible acc. testing - no dynamic effect - protection from corrosion	- reduced lifetime - dep. of environment on friction & lifetime - possible solid debris - possible instabilities - no heat evacuation

4. An example: the typical behaviour of MoS2 coating

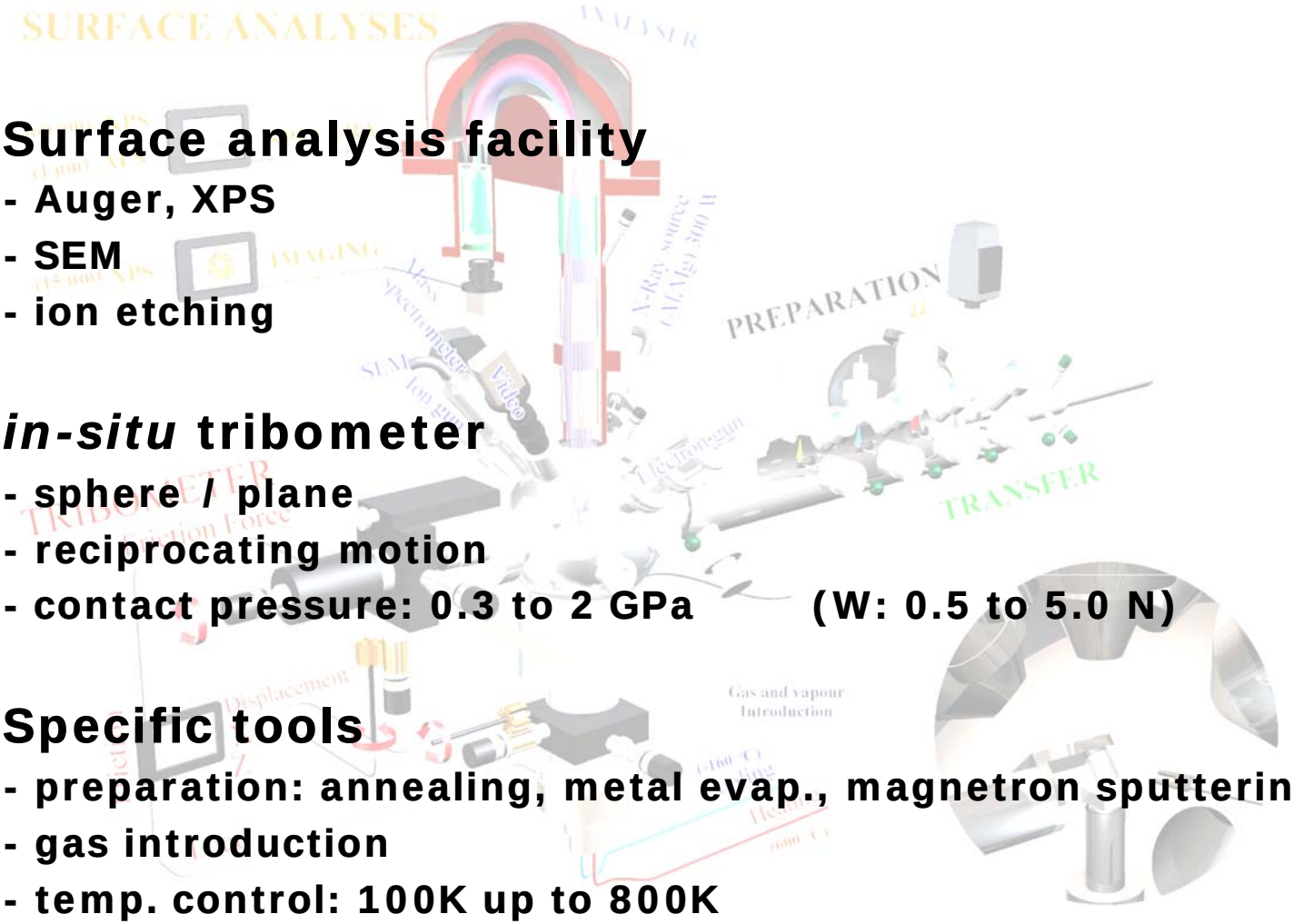
diff environments

life time

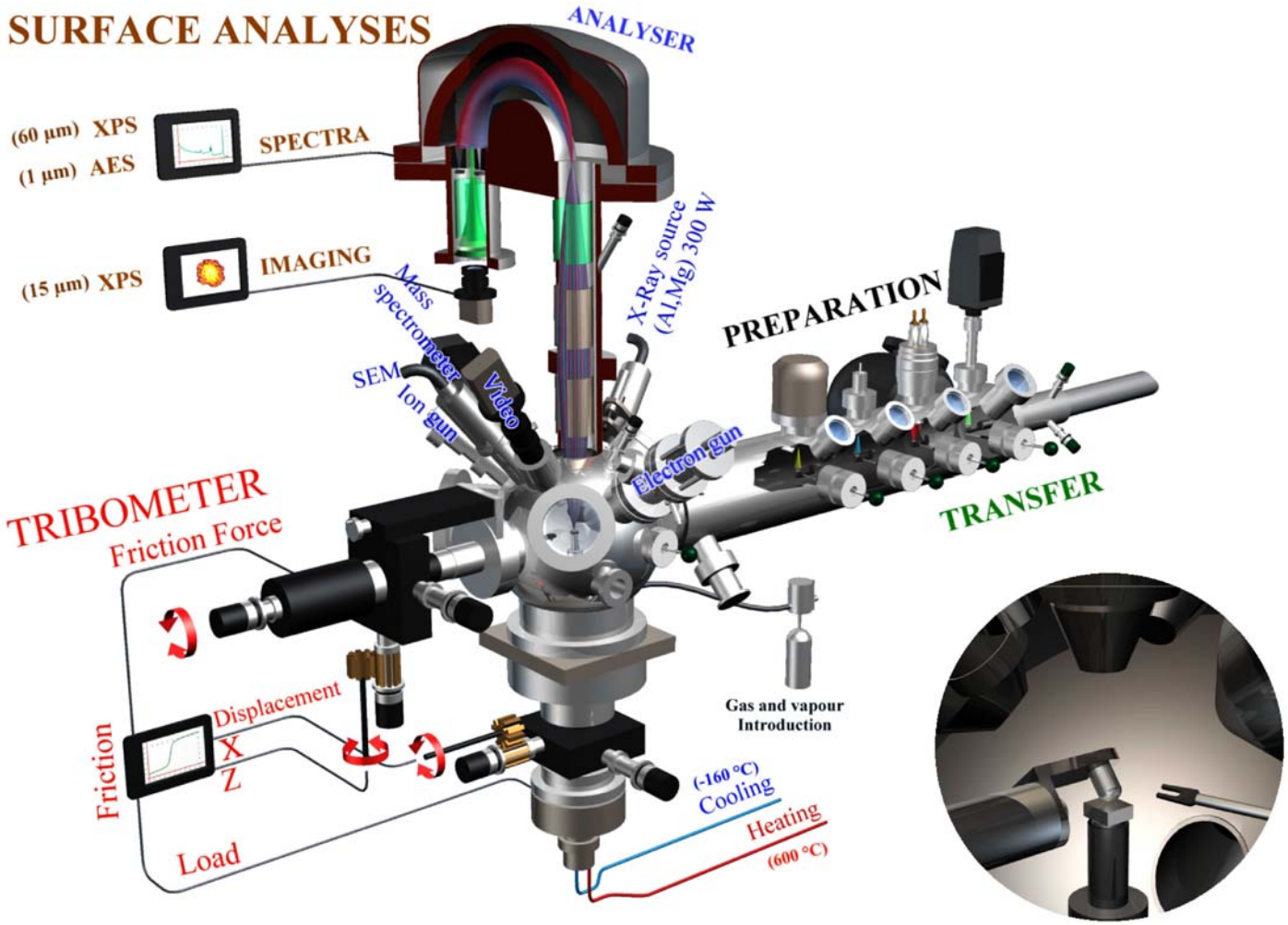
cycle to failure CtF



4. Experimental simulation



- **Surface analysis facility**
  - Auger, XPS
  - SEM
  - ion etching
- ***in-situ* tribometer**
  - sphere / plane
  - reciprocating motion
  - contact pressure: 0.3 to 2 GPa (W: 0.5 to 5.0 N)
- **Specific tools**
  - preparation: annealing, metal evap., magnetron sputtering
  - gas introduction
  - temp. control: 100K up to 800K


SURFACE ANALYSES
ANALYSER
(60 µm) XPS
(1 µm) AES
SPECTRA
(15 µm) XPS
IMAGING
Mass spectrometer
X-Ray source (Al,Mg) 300 W
PREPARATION
SEM
Ion gun
Video
Electron gun
TRANSFER
TRIBOMETER
Friction Force
Displacement
X
Z
Friction
Load
Gas and vapour Introduction
(-160 °C)
Cooling
Heating
(600 °C)

■ Some fundamental studies

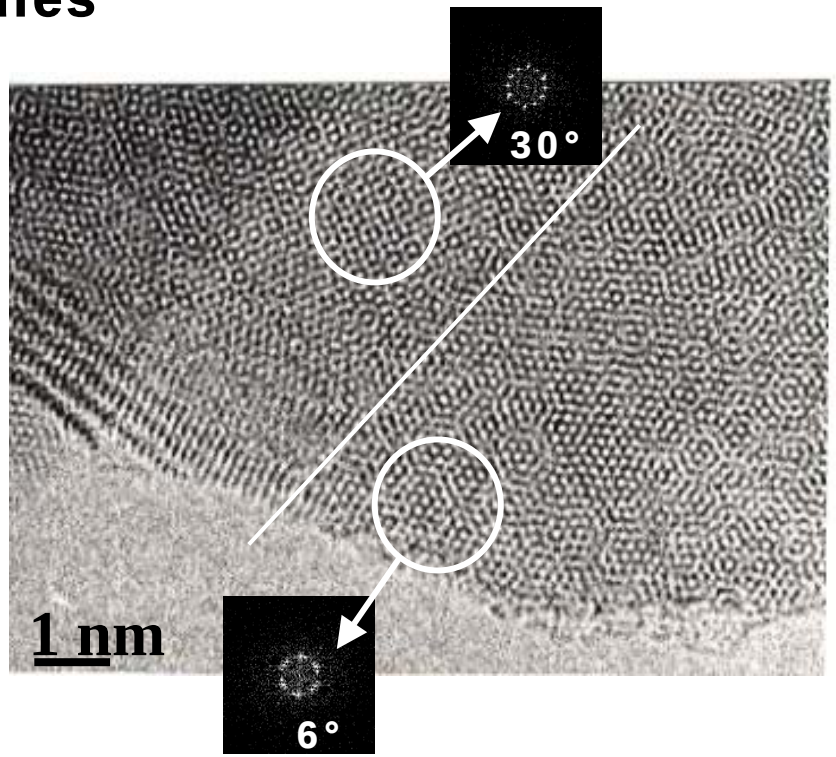
- MoS_2

supra friction

anisotropy in f

MARTIN J.M et al. (1993)

- Carbon-based films



■ Applied projects

- Electrical contacts

  adhesion & seizure concerns

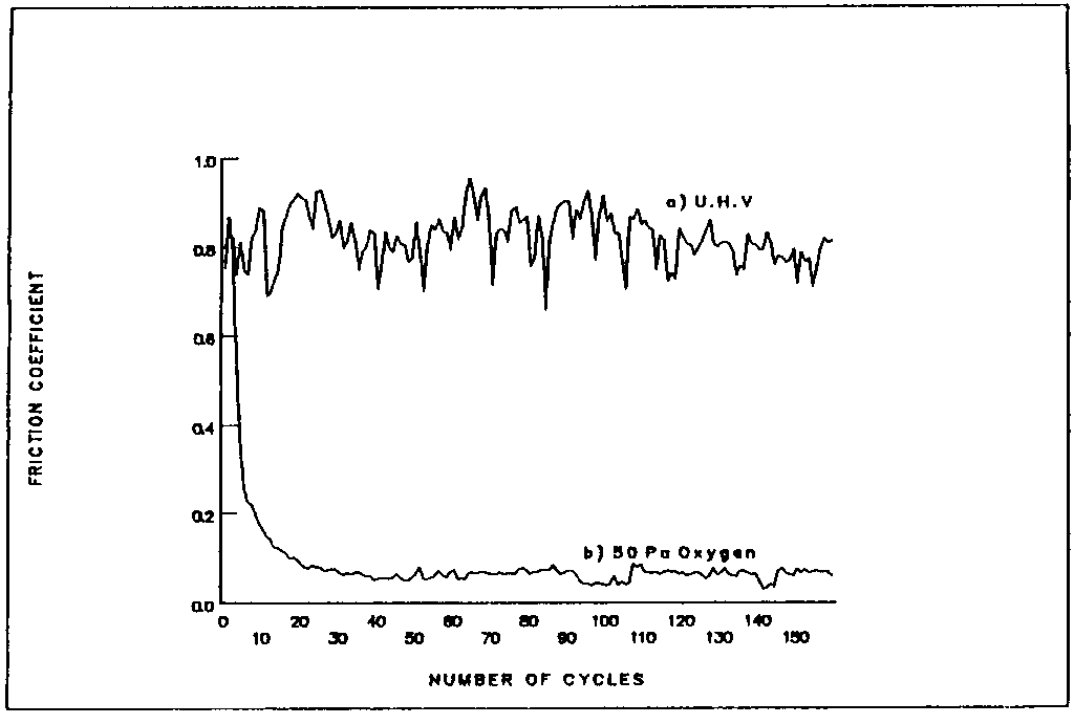
- Coatings for hi precision accelerometers

  lo wear, no debris

■ an example: the behavior of SiC / SiC

the oxygen effect of 50 Pa O_2

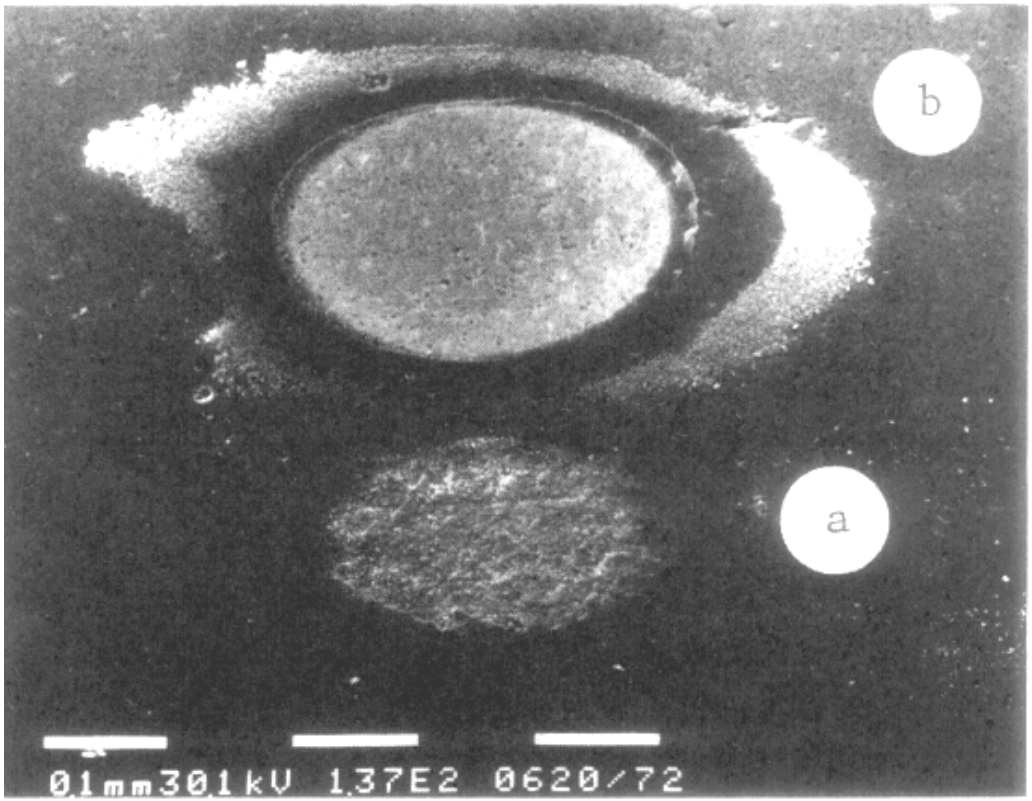
MARTIN J.M. *et al.* (1990)



- ▶ **evidence for the effect of environment**
- ▶ **friction level ÷ 8**

b. O_2 gas, 50 Pa
f= 0.1

a. UHV
f= 0.8



- strong difference between wear scars
- UHV: hi friction / lo wear
- 50 Pa O_2: lo friction / hi wear + debris

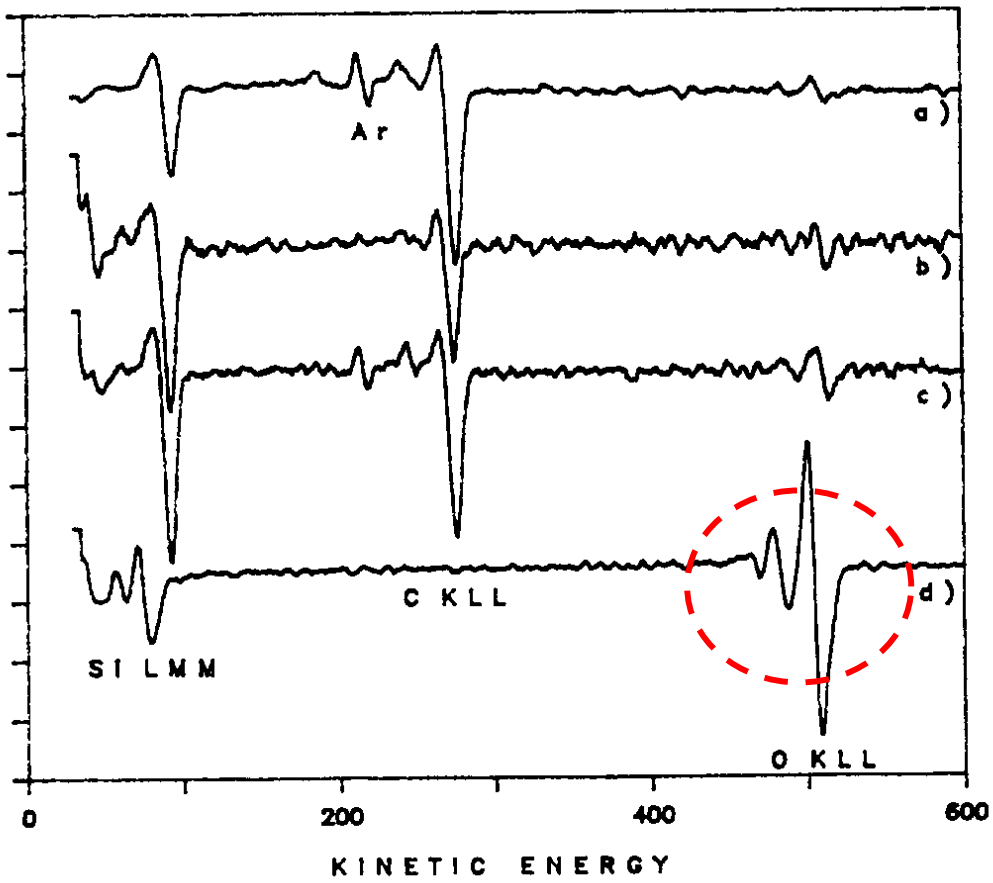
AUGER analysis of the wear tracks

a. UHV, outside

b. UHV, inside

c. 0_2, outside

d. 0_2, inside

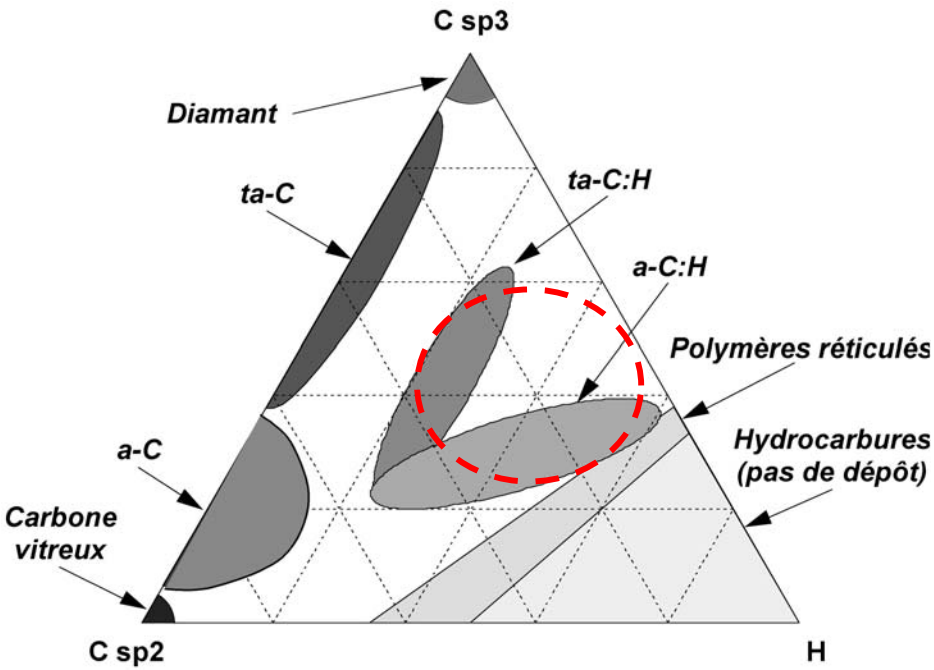


- Auger surface analysis of wear scars
- with O_2 gas: evidence for SiO_x formation
- "tribochemistry"

5. Carbon-based coatings

- **A wide family of materials**
  - from polymers to diamond
  - C sp^2 and C sp^3
  - various H % content

- **Deposition techniques**
  - PVD, PACVD
  - ..



ROBERTSON

■ Hi performance

- good adherence
- hi mechanical properties
- relation composition / structure

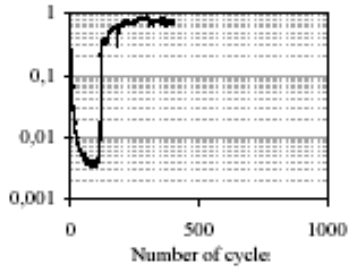
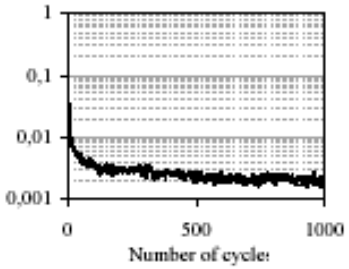
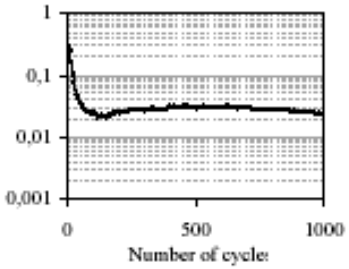
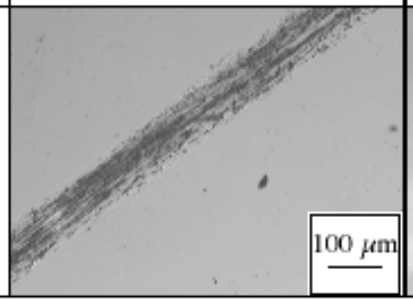
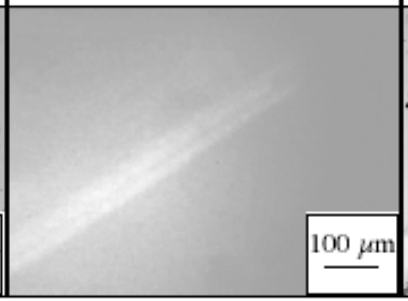
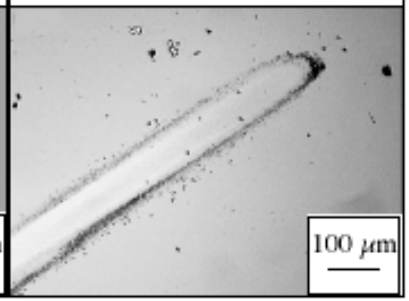
■ Recent study for space application

- CNES *Centre National des Etudes Spatiales* (Fr)
- HEF Group coatings supplyer
- LTDS CNRS research lab. (Fr)

■ Different model coatings

- H:DLC (hydrogenated diamondlike coatings)
- variable H content, by changing the process parameters
- typical thickness: 2 microns (underlayer+coating)
- tribological characterization in air, gas (N_2, O_2, Ar), UHV

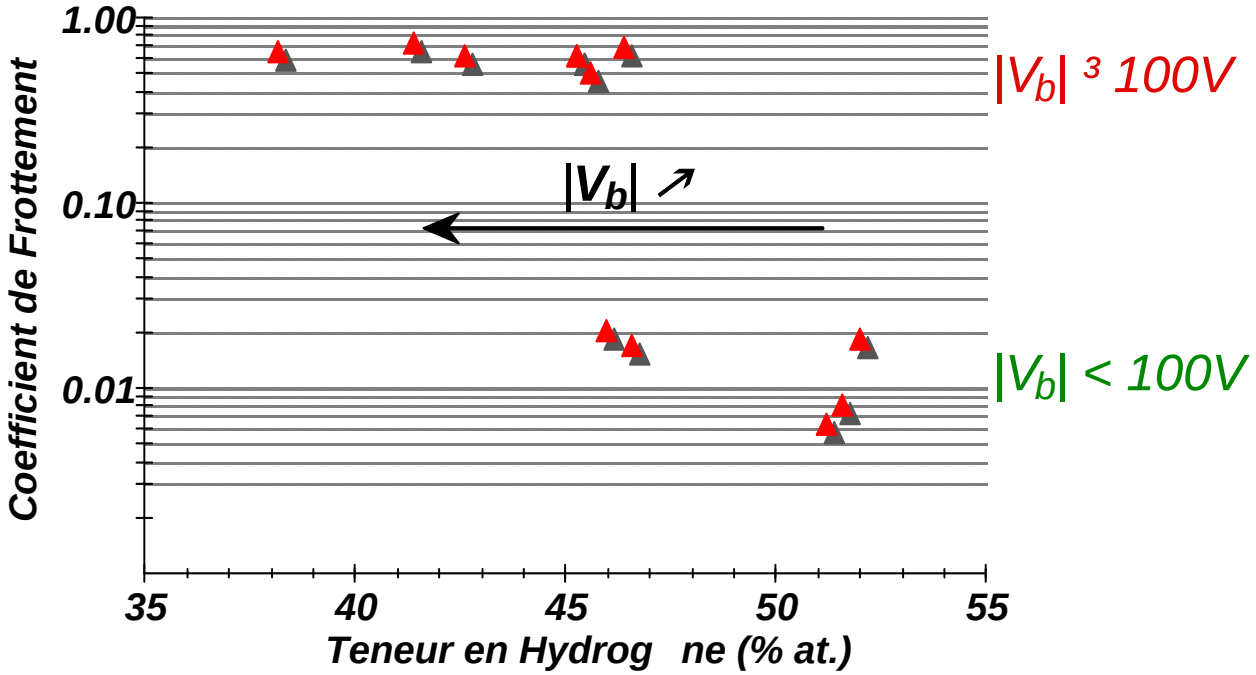
hardness	**13 GPa**	**11 GPa**	**1.3 GPa**
viscoplastic exponent	*0.014*	*0.068*	*0.076*

Sample	***AC8***	***AC5***	***CY5***
Precursor	C_2H_2	C_2H_2	C_6H_{12}
Bias / Pressure	-800 V / 100 mTorr	-500 V / 200 mTorr	-500 V / 200 mTorr
C sp^2 : C sp^3 (%)	70 : 30	65 : 35	56 : 44
Hydrogen content	34 %	40 %	42 %
Bonded H% (FTIR)	57 %	73 %	100 %
Bonded H% (RMN)	93 %	98 %	100 %
Friction coefficient			
Wear track			

■ Optimization of H:DLC coatings

- influence of the polarization bias
- deposition at 2A, bias ranging from -35 à -260 V

FONTAINE J. (2000)



▶ **major influence of H% content on friction in UHV**

▶ **evidence for a threshold in H content**

- millirange f values can be reached
- stable value
- good stability, long lifetime
- near zero debris

■ **On the way...**

- optimization by metal doping of coatings
- effect of radiations, particles
    - atomic oxygen (low earth orbit flight simulation)
    - UV
    - e-

6. Conclusions & perspective

1. **Vacuum tribology is highly specific**
   - high friction, adhesion, dramatic seizure

2. **Comparison of SR instrumentation and space applications**

3. **Development of "experimental modelling" of tribosystems in vacuum**
   - dedicated facility & expertise
   - fundamental studies & testing real world solutions

4. **Solid lubricants are good candidates in vacuum SR instrumentation.**
   - the solutions developed for space applications are not necessary directly applicable.

Aknowledgments

- **The organizers**
- **CNRS**

  for financial support

- **Masanori IWAKI**

  JAXA (Japan), invited Y2004 at LTDS

thank you for attention

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