Effects on spacecraft materials

Atomic Oxygen

Daniel **Lubián Arenillas**

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LEO environment

↓

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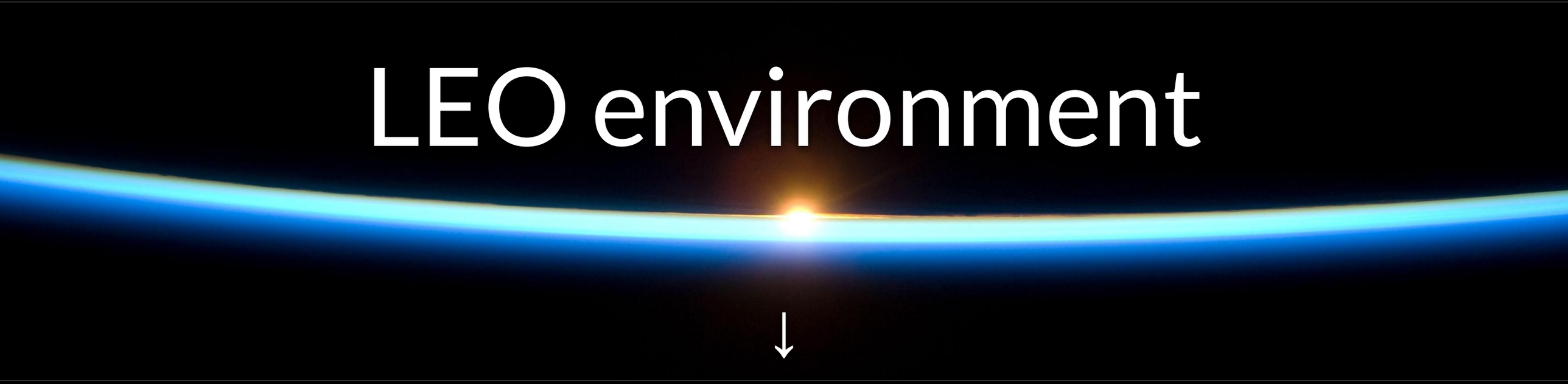
Erosion

Structure modification

Surface roughening

↓

LEO environment



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Properties

Optical

Thermal

Electrical

Mechanical

Atomic oxygen

O_2 + UV radiation

↓

$2\,O\cdot$

(99%)

↓

$O^+ + O^-$

(1%)

Atomic oxygen

Present in upper atmosphere

200 - 700 km → most important species

Density

↑

Altitude, solar activity, time of year, orbit inclination

Atomic oxygen

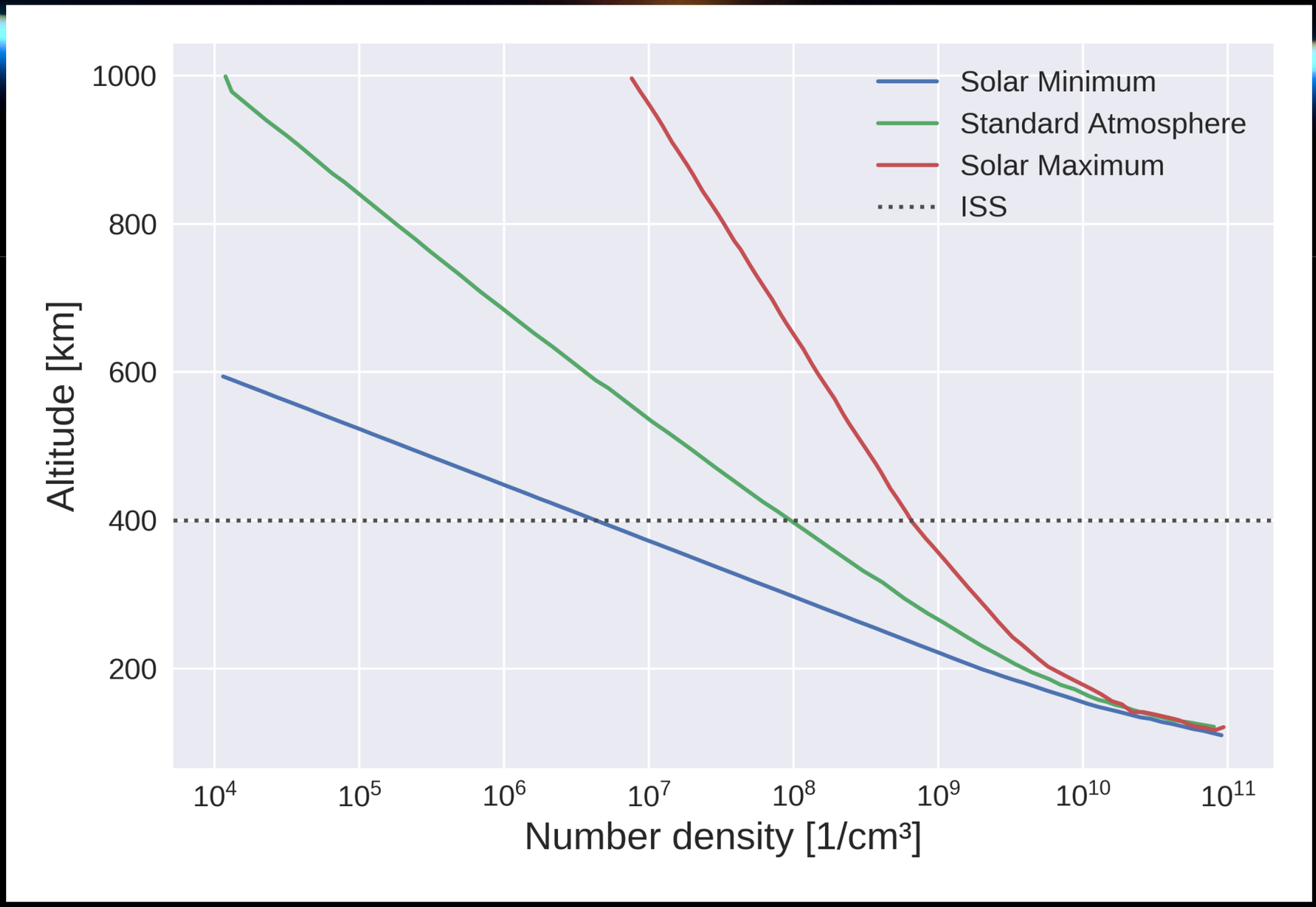
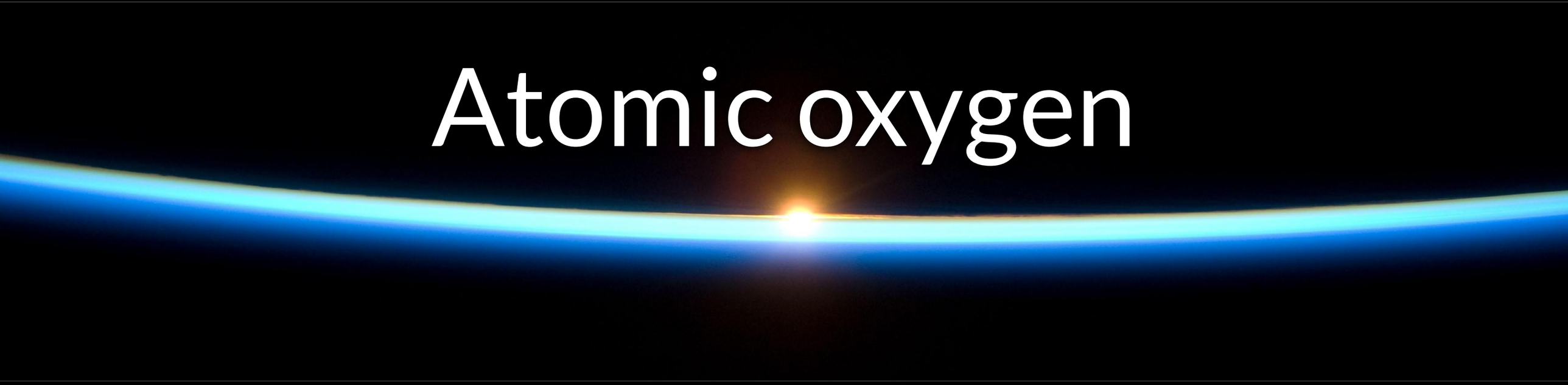


Fig. 1 - Atomic oxygen flux versus altitude. Adapted from [2].

Atomic oxygen



$O\cdot$, O^+ , O^-

Very reactive

+

UV radiation weakens molecular bonds

Atomic oxygen

Relative velocity spacecraft-ATOX very high

↓

High collision energy

↓

More reactivity

Effects on metals

In general, no macroscopic effects

Most aluminium alloys are resistant, but

2090 Al-Li → loss in superficial Li

Silver and osmium react very rapidly

Effects on metals

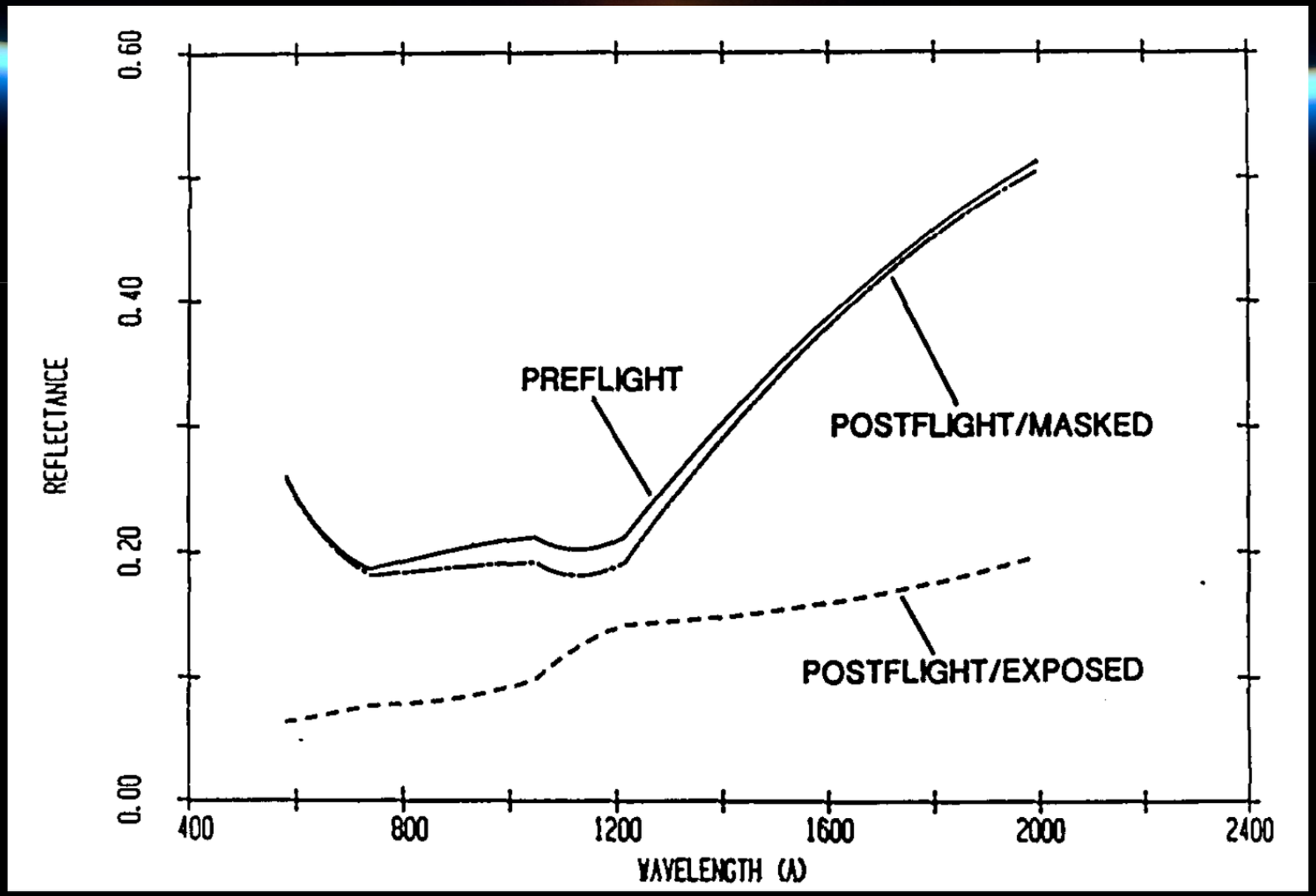


Fig. 3 - Effect of LEO environment on the reflectance spectrum of exposed and masked portions of a 200 Å thick osmium film with chromium undercoat. Extracted from [4].

Effects on metals

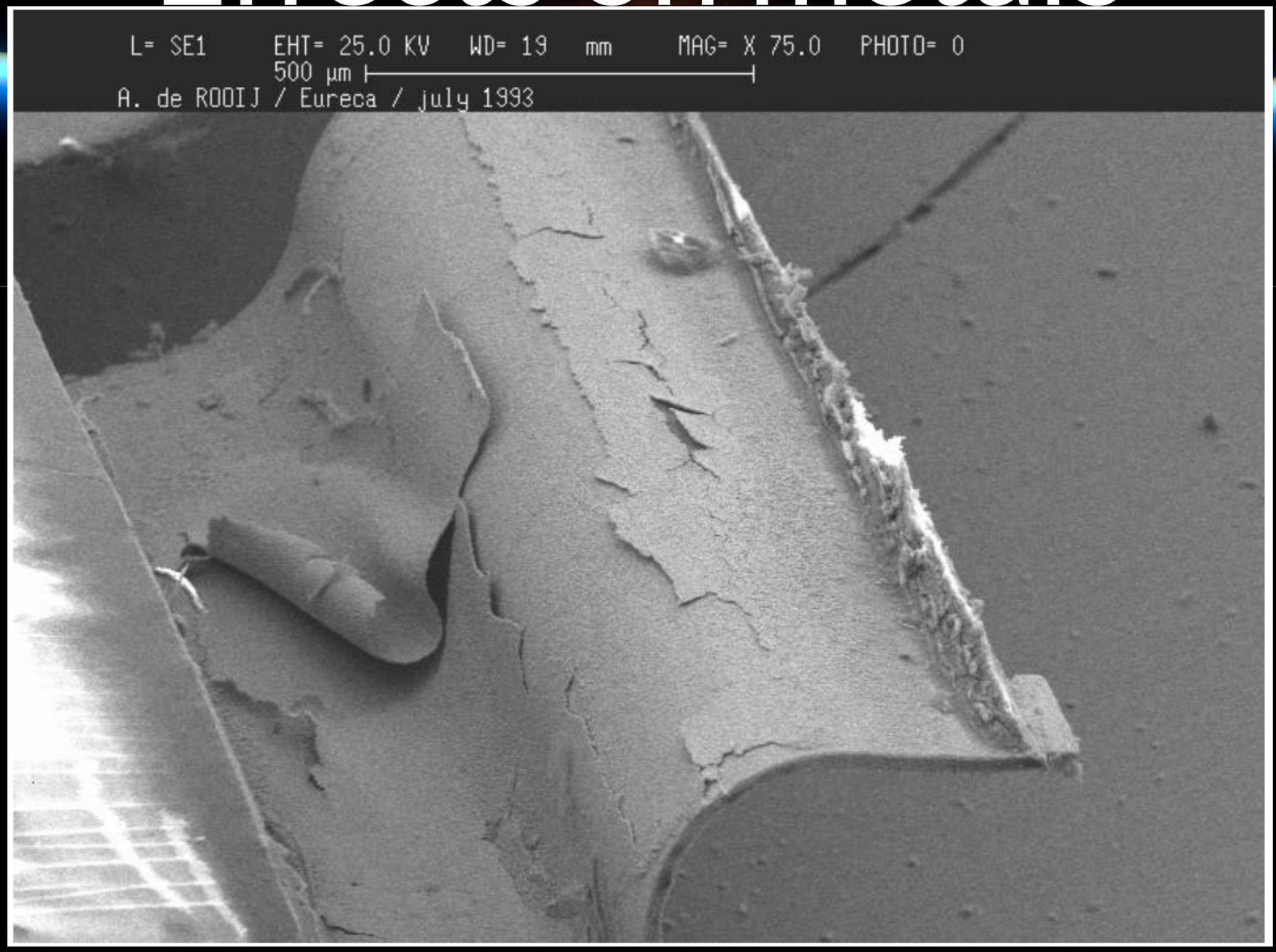


Fig. 4 - Silver interconnector (25 µm) retrieved from Eureca. Extracted from [6].

Effects on organic substances

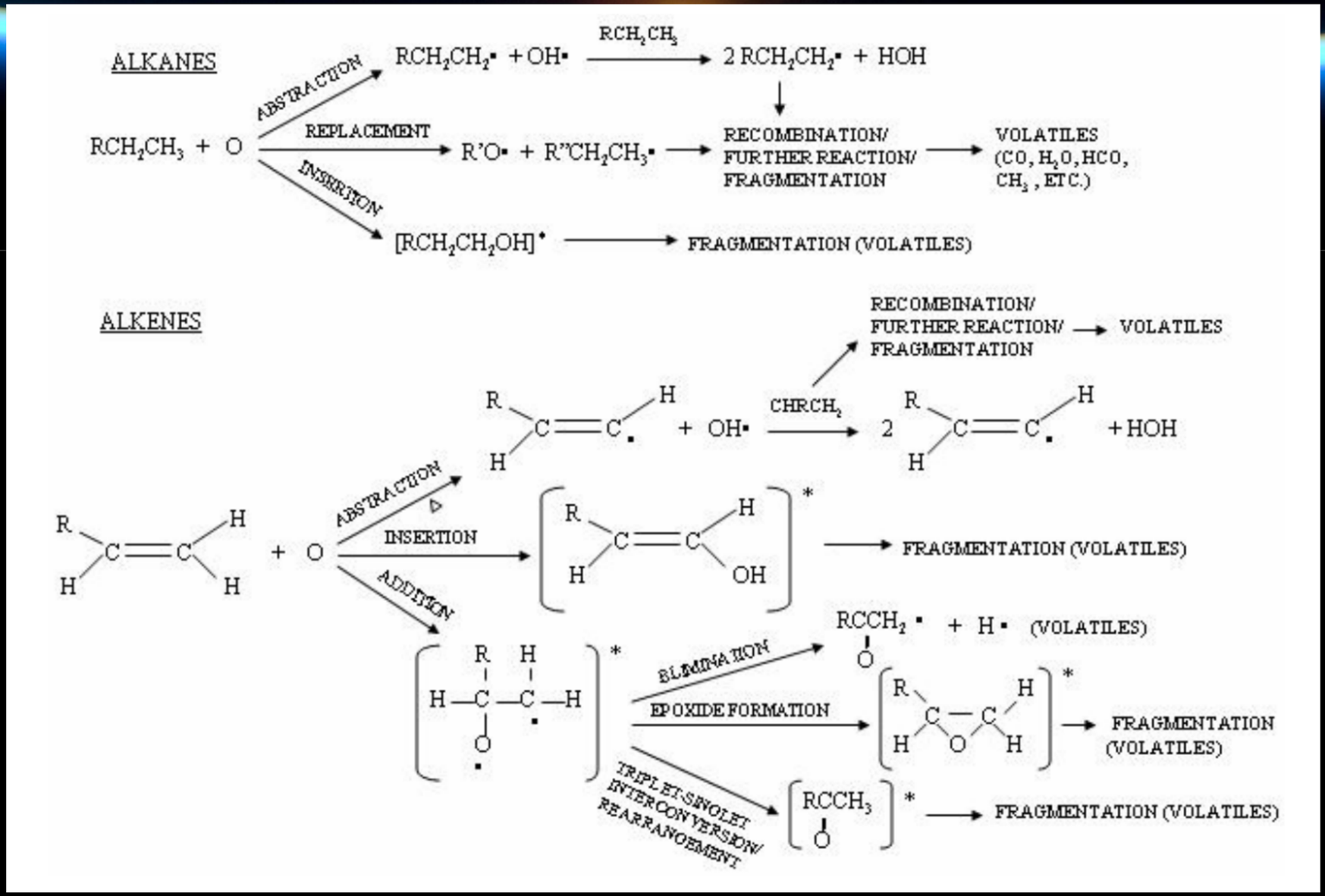


Fig. 5 - Atomic oxygen reaction pathways with polymers. Extracted from [2].

Effects on organic substances

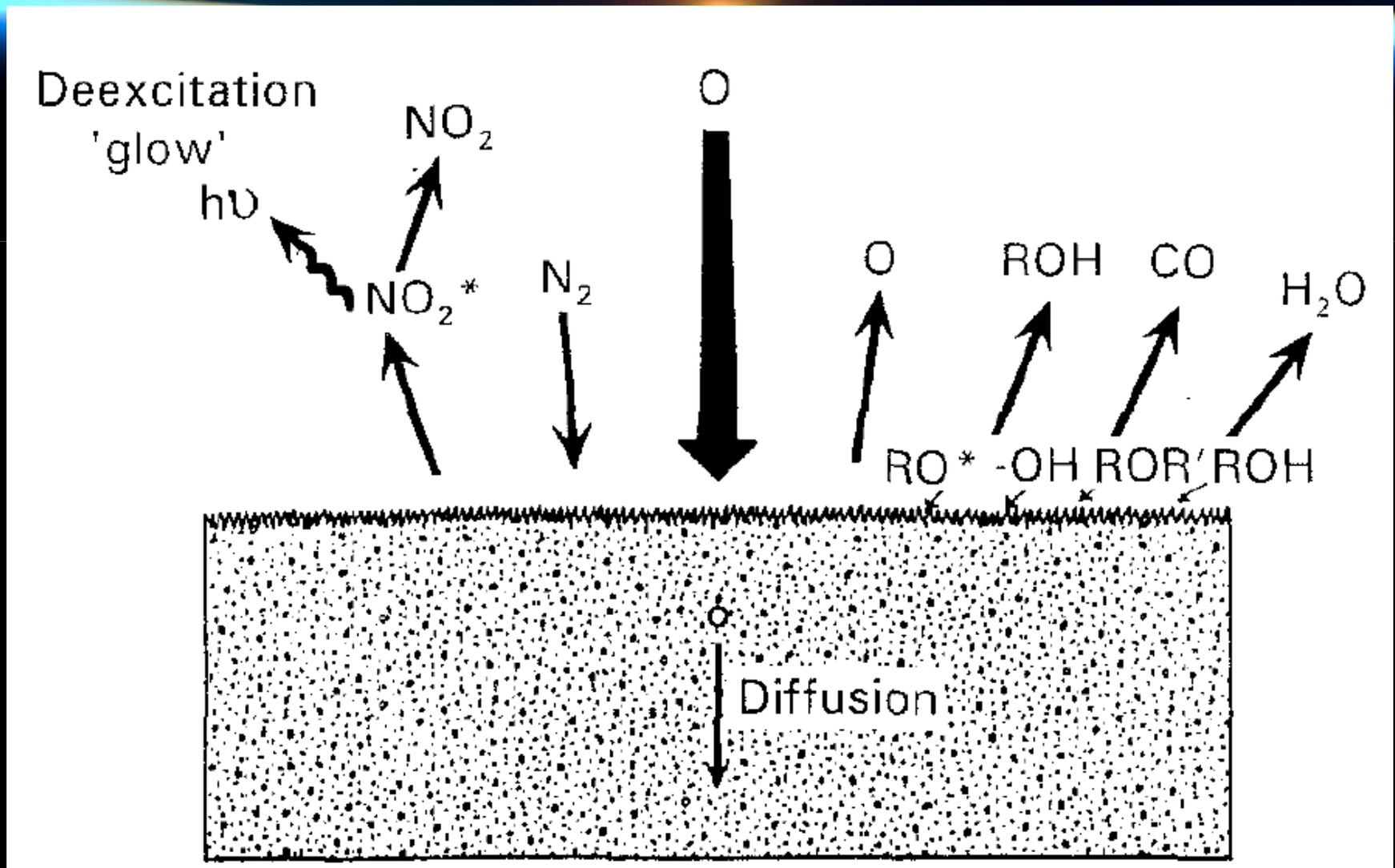


Fig. 6 - Interaction of atomic oxygen with organic materials. Extracted from [7].

Effects on organic substances

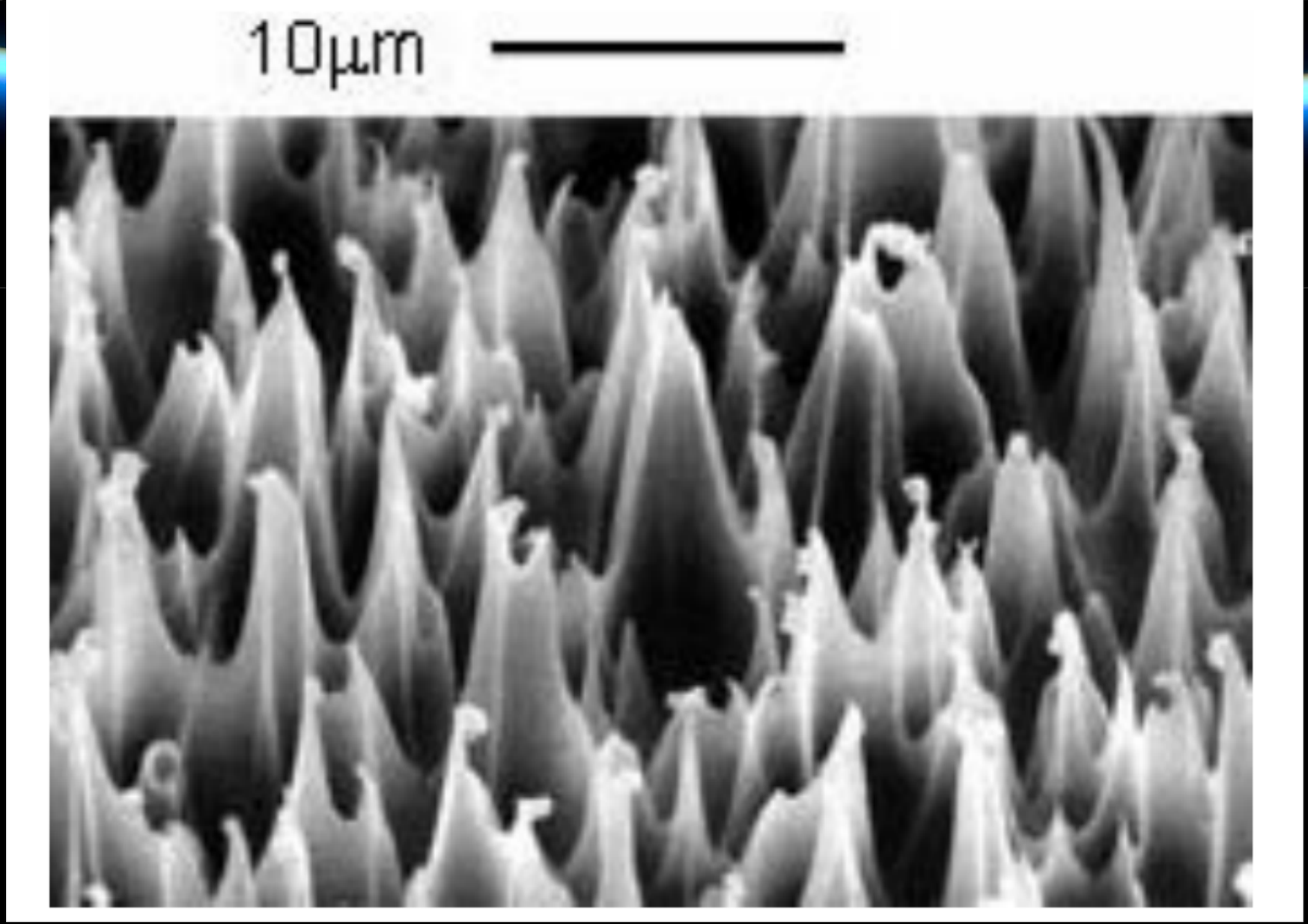


Fig. 7 - Chlorotrifluoroethylene after an atomic oxygen fluence of 8.99×10^{21} atoms/cm^2 at 8.1 degrees off ram. Extracted from [4].

Effects on organic substances

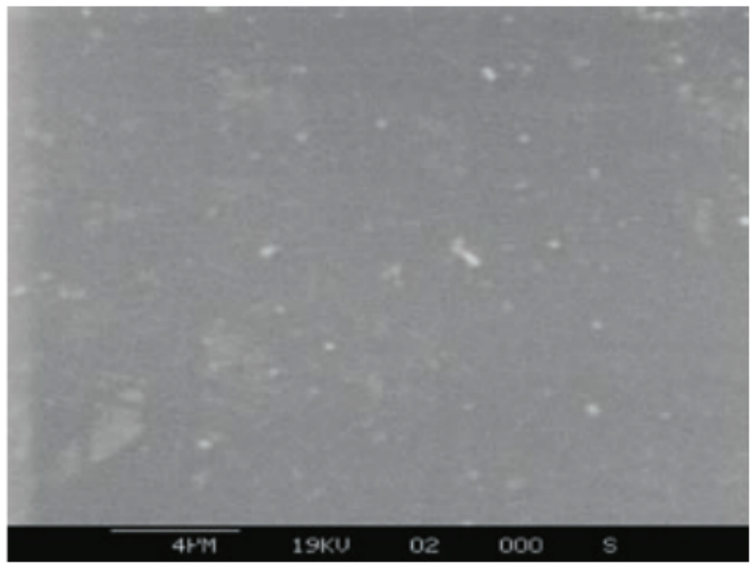


Figure 5. SEM photograph of the sample before the AO exposure experiment.

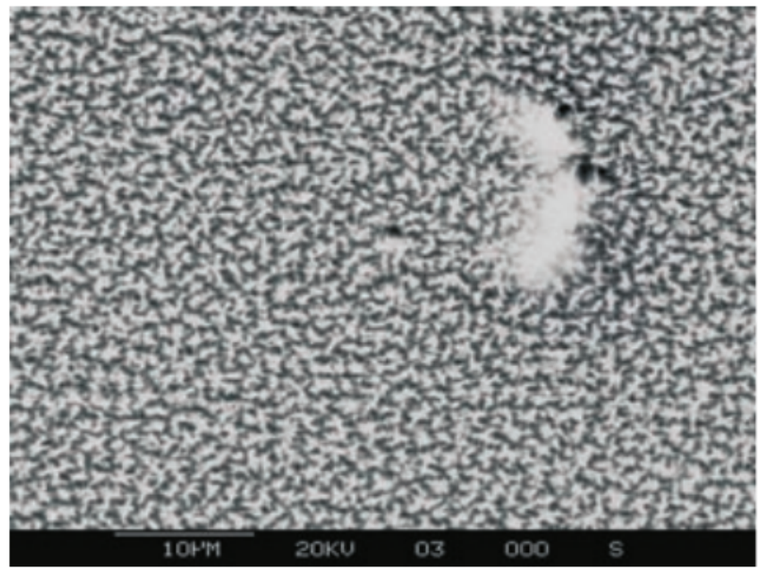


Figure 7. SEM photograph of the sample after the 3.07×10^{20} atoms cm^{-2} AO exposure experiment.

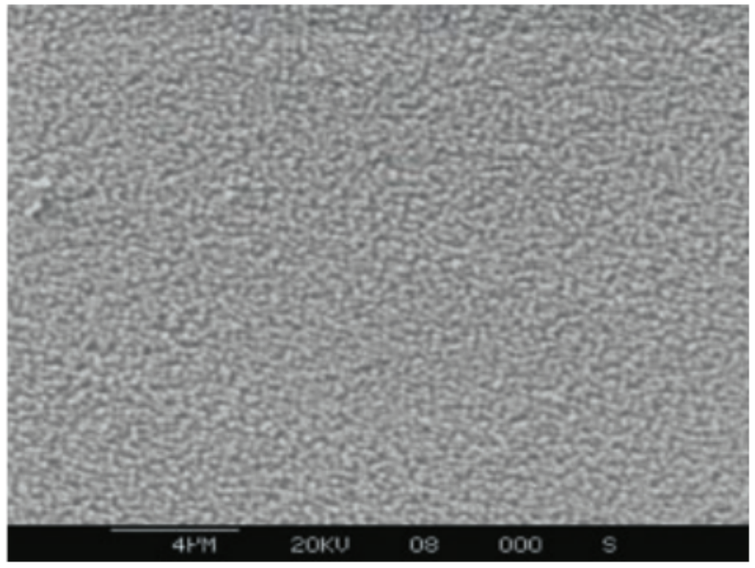


Figure 6. SEM photograph of the sample after the 7.13×10^{19} atoms cm^{-2} AO exposure experiment.

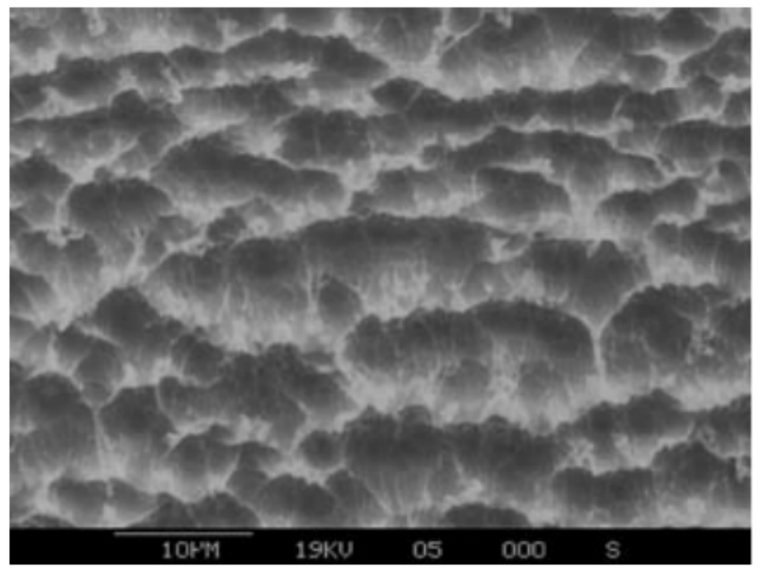
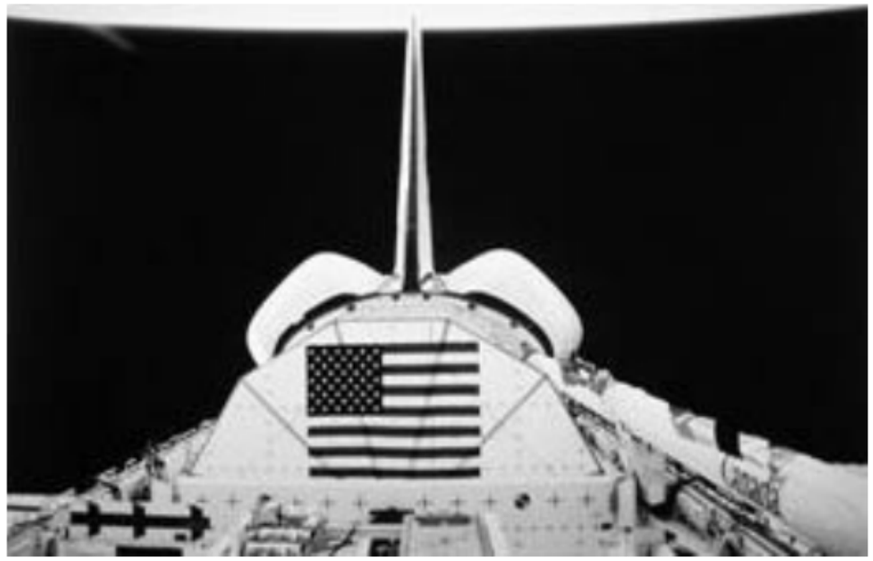


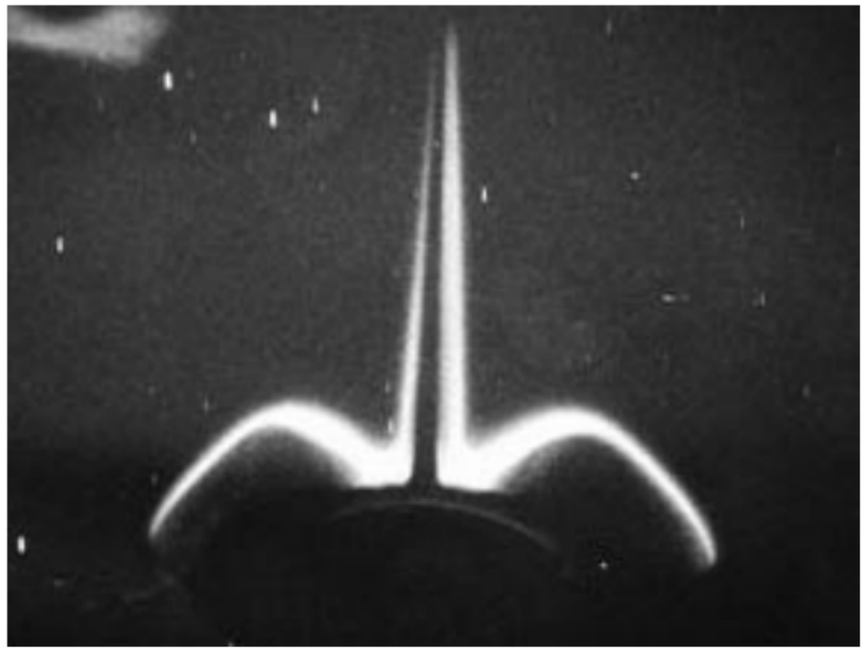
Figure 8. SEM photograph of the sample after the 9.9×10^{20} atoms cm^{-2} AO exposure experiment.

Fig. 8 - Extracted from [8].

Effects on organic substances



(a) Photograph of space shuttle during daylight



(b) Photograph of space shuttle at night

Fig. 2 - Low Earth orbital glow phenomena. Extracted from [2].

Examples

THERMAL CONTROL

Metallized polymer films

Second surface mirrors (SSM)

Multilayer insulators (MLI)

- Silver-backed FEP Teflon
- FEP Kapton
- Aluminized Kapton

Examples

THERMAL CONTROL

Organic paints

Parabolic communication antennae

Rear side of solar panels

- White paint: Chemglaze A276 = TiO_2 + polyurethane
- Black paint: Chemglaze Z302 = C + polyurethane

Examples

SOLAR PANELS

Honeycomb sandwich structure: glass fibre + aluminium

Kapton

Silver conectors

MgF_2: antireflection coating

Possible solutions

Application of thin film protective coatings made of atomic oxygen durable materials

100 - 600 nm

SiO_2, Al_2O_3, In, Ge, Al, Au...

Sputter or vapor deposition

Possible solutions

Modification of the surface of the polymers to make them more durable to atomic oxygen

Possible solutions

Use of alternative polymers that contain metal atoms which develop a protective coating with atomic oxygen exposure

Conclusions

Atomic oxygen is an important degradation agent in LEO

Atomic oxygen affects mainly organic components, key in thermal control and solar cells

Atomic oxygen effects can and should be mitigated in long missions

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