A New Look into NASA's Pioneering Atomic Oxygen Treatment Removing Lipstick Defacement from Andy Warhol's "Bathtub" (1961)

MOXY PROJECT — Green Atmospheric Plasma Generated Monoatomic Oxygen Technology for Restoration of the Works of Art. Funded by the European Union – Horizon Europe

Tomas Markevicius (1), Nina Olsson (2), Anton Nikiforov (3), Agnieszka Suliga (4), Gianluca Pastorelli (5), Nan Yang (6), Silvia Pizzimenti (7), Geert Van der Snickt(6), Klaas Jan van den Berg(8), Catarina Pires (8), Emilie Froment (8), Ilaria Bonaduce(7), Ana Sobota (9), Dieuwertje Schrijvers (10), Michail Poupouzas (9) Jurate Markeviciene (2), Michaela Florescu (11), Alison Norton (11), Marta Cremonesi (6), Aiste Galaunyte (2),

(1,3) Ghent University, (2) ICOMOS Lithuania, (4) European Space Agency ESA-ESTEC, (4) National Gallery of Denmark, (5) University of Antwerp, (6) University of Pisa (7), University of Amsterdam (8), Eindhoven University of Technology (9), WeLoop (10), Moderna Museet (11)

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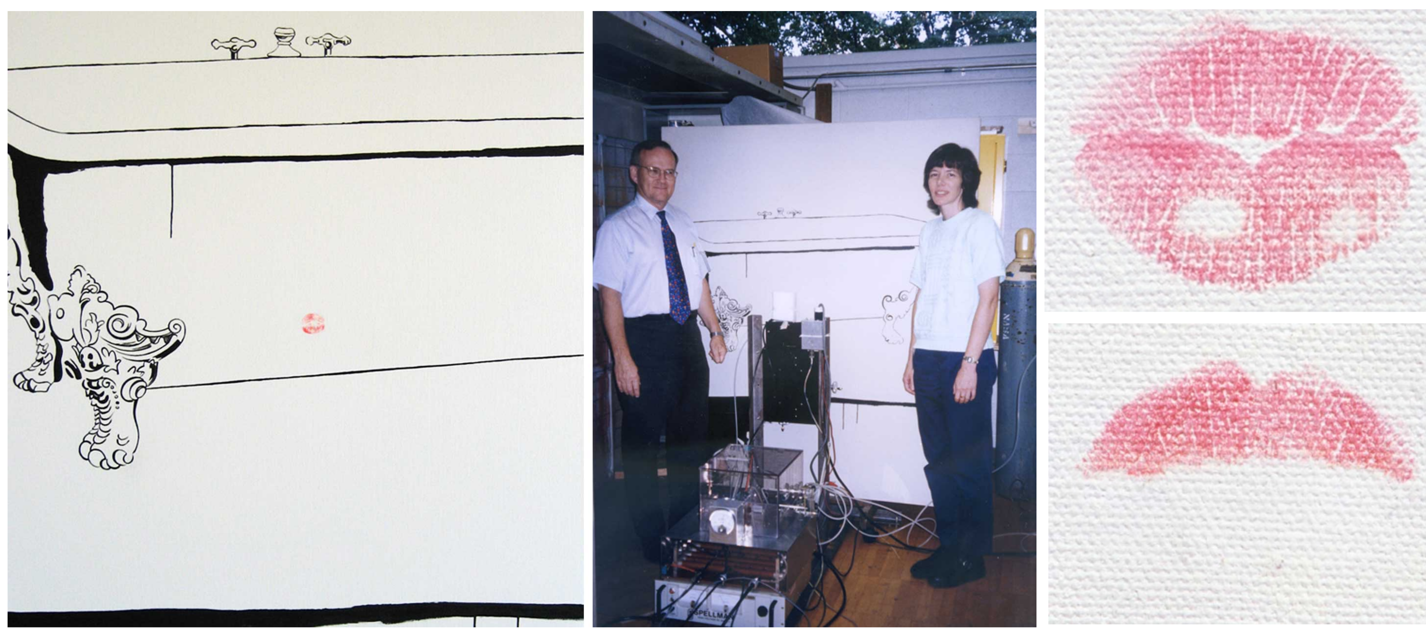
NASA's contribution to multiple radical innovations and technologies which have become essential to society is difficult to underestimate: from LASIK eye-tracking technology in eye surgery, to ACTIS from the Apollo mission which made CAT scans possible, to polycrystalline alumina used in invisible dental braces, to insulin pumps, scratch-resistant lenses and many others. Atomic oxygen (AO) may become a groundbreaking NASA contribution to art and cultural heritage; it has unique potential for non-contact and solvent-free cleaning of otherwise problematic, porous and fragile materials that cannot tolerate mechanical wet or dry cleaning. AO research continues in the MOXY project **www.moxyproject.eu**

AO technology, currently developed by the MOXY Horizon Europe project (2022-2026), in the context of green technologies for cultural heritage, has its origins in a serendipitous invention, as it started with a defacing lipstick kiss on Andy Warhol's painting Bathtub (1961) at The Andy Warhol Museum in Pittsburgh in 1997. Lipstick is designed for porous substrates, such as human skin, and may be extremely difficult to safely remove from delicate porous modern materials, such as the acrylic paints used by Andy Warhol.

Eva Szabo Cosmetics Shade 302 Coral lipstick, which was used to deface the Andy Warhol painting in 1997. Image: NASA. Sample was provided to MOXY researchers for testing and benchmarking.

In fact, in a 1980 interview, Andy Warhol deliberated with Paloma Picasso: *"I never understand how the lipstick business goes on because lipstick lasts forever"* [1]. When a lipstick-wearing visitor kissed the Bathtub at an event in 1997, the prospects of the damage lasting forever seemed dreadfully true, as the lipstick could not be removed. Ellen Baxter, the former chief conservator in charge of the treatment, noted that *"Of all the paintings there for her to put her lips to, that was the worst one… I couldn't use typical conservation methods to clean it… It was like trying to take a lipstick stain out of a piece of Kleenex"* [2]. Conservators turned to NASA where Bruce Banks and Sharon Miller were investigating AO erosion on spacecraft materials and had already tested AO treatment under low pressure for fire-damaged paintings [3]



NASA scientists Bruce Banks and Sharon Miller during A. Warhol's "Bathtub" (1961) treatment in 1997. Cleaning tests on mock-ups using atmospheric AO. Images: NASA

The bathtub required a targeted treatment without placing the painting in a low-pressure chamber, and Banks and Miller pioneered an atmospheric AO apparatus which was moved to the museum and used to remove the lipstick without physically touching the surface [2]. The treatment made headlines in the 1990s but was never repeated until recently when MOXY researchers in collaboration with the European Space Agency (ESA) began experimenting with AO on typical cultural heritage materials using their low Earth orbit oxygen environment simulator, LEOX and to develop an innovative atmospheric AO technology in the MOXY project [4] **www.moxyproject.eu** Instagram: **@moxy.project**

ATOMIC OXYGEN

Nascent (atomic) oxygen (AO) at ground state O (^{3}p), investigated by MOXY has very different properties from the oxygen molecule O_2 that we breathe and is even more different than ozone O_3. AO is a space environment element, present in the region known as LEO: low Earth orbit (80 - 1000 km) and is extremely short-lived on the ground (a few milliseconds).

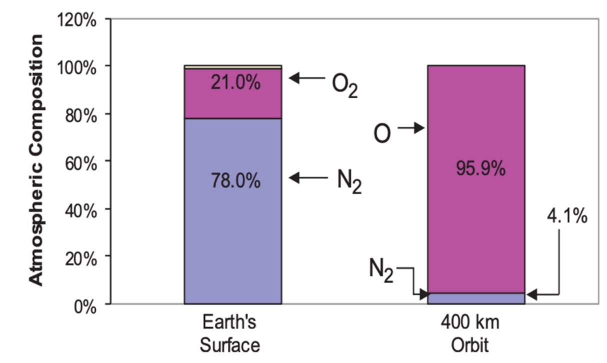
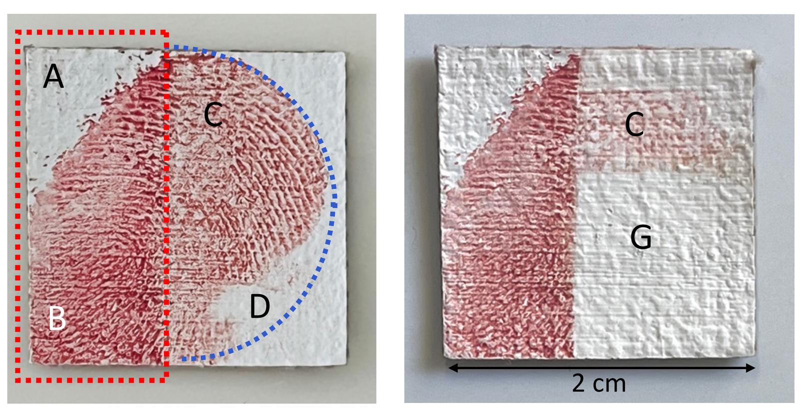


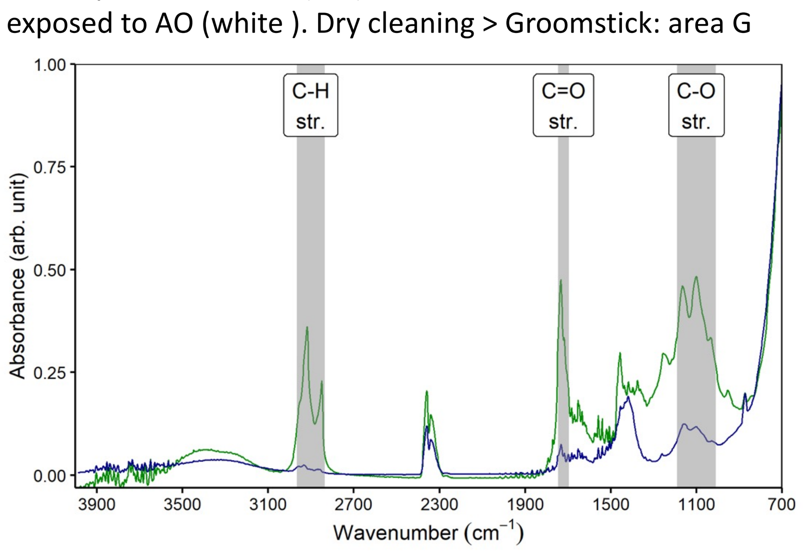
Image: Sharon Miller, NASA

In space, AO is produced by the dissociation of O_2 by UV radiation. AO is highly unstable and reactive, and in space exists without recombination since only about 10^9 atoms are found in 1 cm^3. However, opportunities for reacting with other atoms are abundant on the ground, which is a challenge to apply AO for conservation treatments in atmospheric, rather than low-pressure conditions.

EXPERIMENTING WITH AO   ANALYTICAL ASSESSMENT

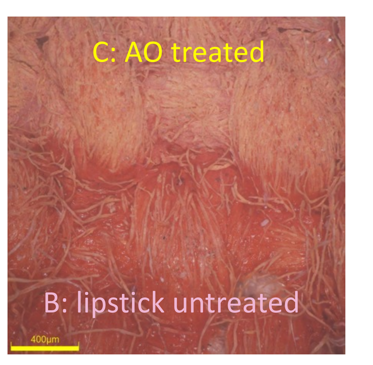


Boho liptick: areas A-B (red) masked from AO, areas C-D: exposed to AO (white). Dry cleaning > Groomstick: area G



FTIR-ATR. Boho lipstick before (blue) and after (green) AO treatment

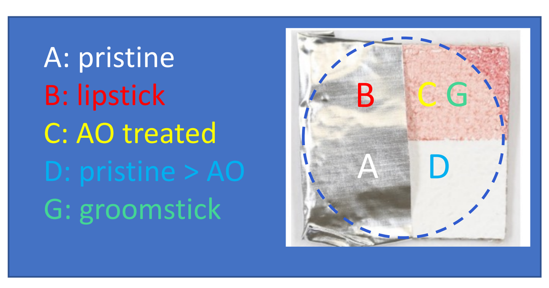
Assessment: FTIR-ATR spectra measured in area B (lipstick - green) and C (AO-treated - blue) show chemical changes to lipstick composition. Reduction of peak intensity in C-H, C=O, C-O stretching bands related to esters and aliphatic compounds indicate the removal of organic binding medium. C-H bonds may be related to beeswax and castor oil, present in the lipstick.



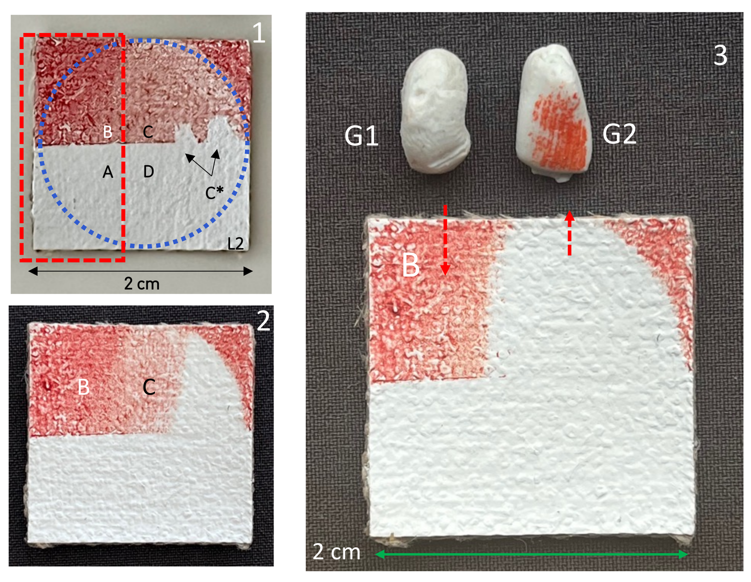
3D digital microscopy. Lipstick before (left) and after AO treatment

Boho lipstick *Desire 312* composition: Castor Oil, Hydrogenated Olive Oil, Stearyl Esters, Oleic-Linoleic-Linolenic Polyglycerides, Carnauba Wax, Candelilla Wax, Carmine Ci 75470, Titanium Dioxide Ci 77891, Iron Oxides Ci 77491, Fragrance, Tocopherol.

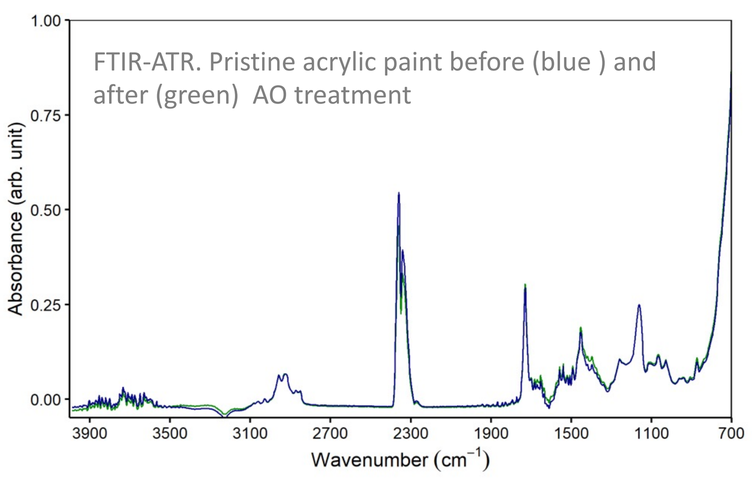
The "Warhol" mockups were prepared using titanium white acrylic paint on canvas. They were soiled with ***Boho Desiree 312*** (# 1342560) lipstick. A sample of unprimed cotton canvas was soiled with ***Maybelline Coral Rise 344*** (#333836). A sample of an **Eva *Szabo Shade 302 Coral*** (raw and on canvas primed with white acrylic paint) was supplied by Bruce Banks. Half of each sample was masked with aluminum foil, and the other half was exposed to AO. 4 areas A-B-C-D were obtained:



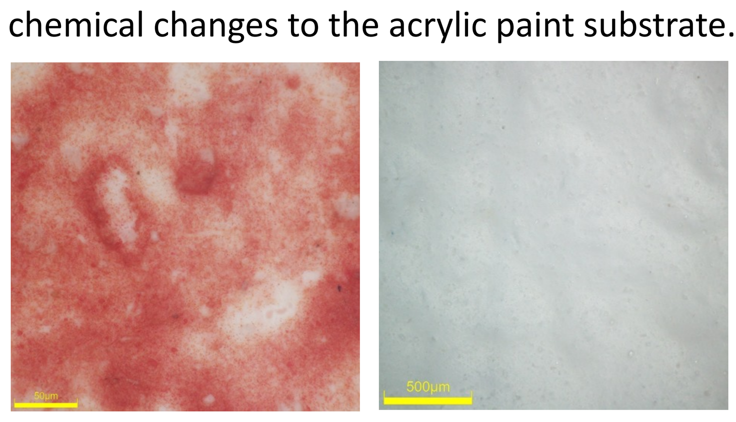
Color measurements: the A vs C bar (turquoise) shows ΔE^*_{00} between pristine and cleaned points. The dotted lines indicate the area between the upper (ΔE^*_{ab} ≈ 2.3) and lower (ΔE^*_{00} ≈ 1.0) limits of a just noticeable difference (JND) [6]. The difference between pristine and cleaned areas was below ΔE^*_{00} meaning effective cleaning.



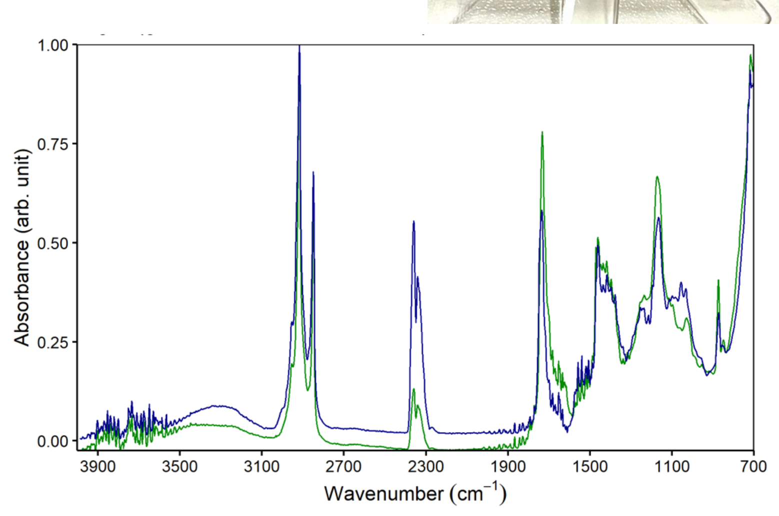
Cleaning process: step 1 (AO) and 2 (groomstick). AO treated lipstick residuum removed (3). Groomstick was effective in AO treated area (C>G2), but ineffective in untreated area (B>G1).



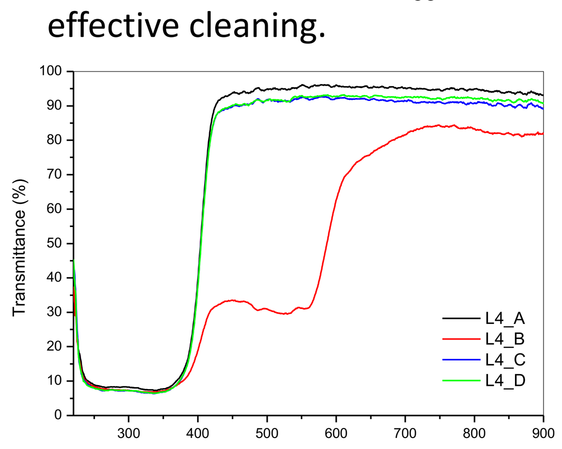
Assessment: FTIR-ATR spectra measured in area A (pristine) and C-G (AO + groomstick) are matching, confirming effective removal of lipstick contaminant without noticeable chemical changes to the acrylic paint substrate.



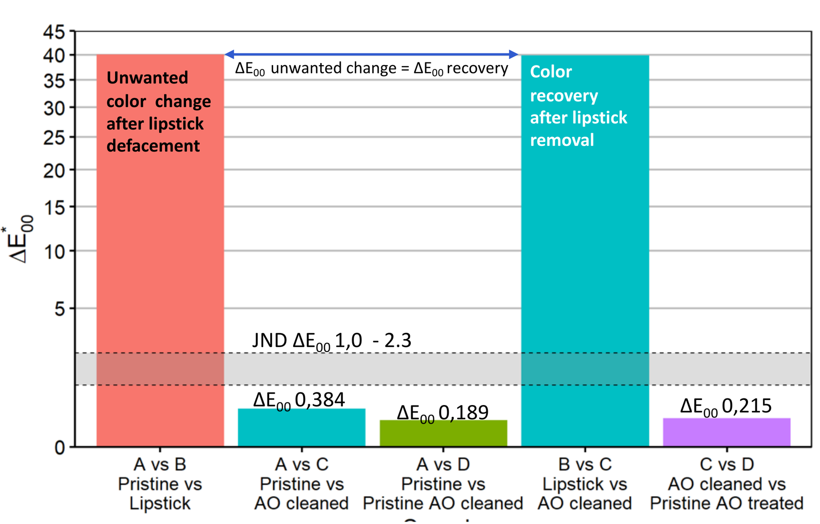
3D digital microscopy. Lipstick before (left) and after treatment (right).



Bruce Banks and Sharon Miller provided a mockup of Eva Szabo lipstick. **FTIR-ATR spectra** of **Eva Szabo (green)** and **Boho (blue)** lipsticks shows close similarity in chemical composition, which indicates that Boho lipstick was a representative model for Warhol treatment deconstruction.

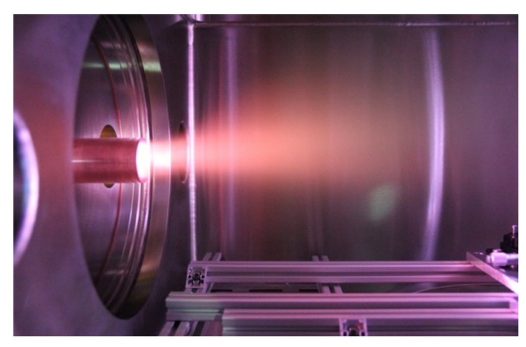


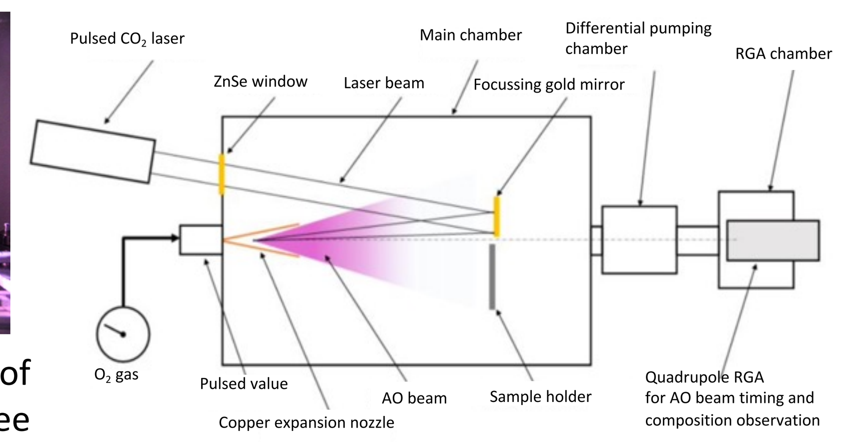
The **diffused reflectance spectroscopy** shows matching spectra for pristine (A) and cleaned (C), and pristine AO treated (D) areas. Significant shift in area (B): lipstick defacement.



The **color change** was compared using CIEDE2000 (ΔE_{00}) CIEL*a*b* color index (ASTM D2244-02).

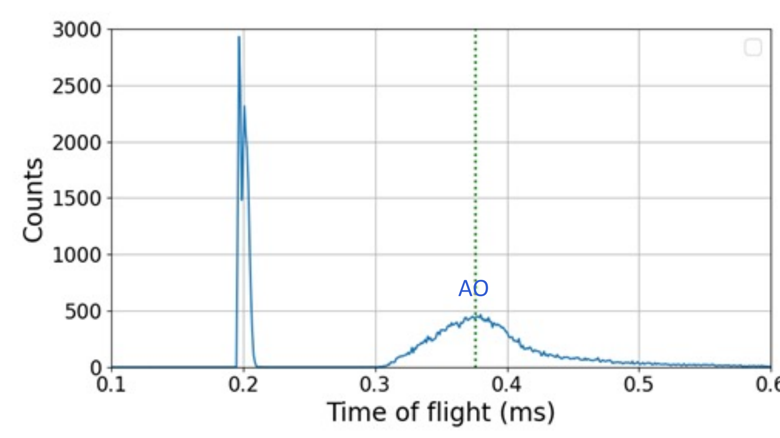
AO CLEANING USING LEOX @ ESA-ESTEC





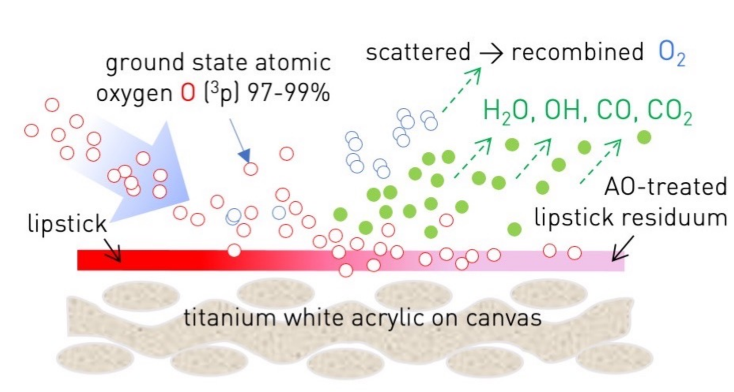
Scheme of the LEOX laser-detonated atomic oxygen

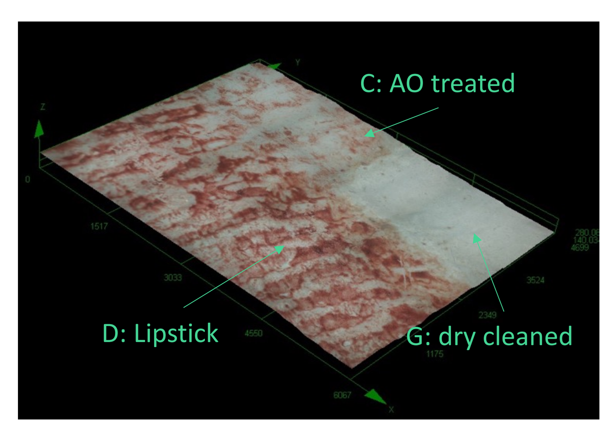
Cleaning proces: LEOX consists of a vessel composed of three compartments separated by an electro-pneumatic valve and an orifice in the main chamber where the samples are exposed to 99% AO under low-pressure conditions. AO was produced using IR CO_2 laser detonation. The kinetic energy of atoms is set at 5eV, like the space environment. In this testing, the exposure time was selected and 54.9 hours with AO fluence 2.49E+21 (At/cm^2) and Flux 7.10E+15 (At/cm^2·sec).



Time of flight mass spectroscopy TOF-MS of AO effluent

AO measurements. The mass spectrometer was used to monitor the quality and energy distribution of the pulsed beam during the AO exposure. The AO velocity was obtained by measuring the time-of-flight TOF with a mass spectrometer tuned to AO m/z = 16 and O_2 m/z=32 (atomic mass units amu) to detect a ratio between AO and O_2. The AO intensity was recorded versus time with a scaler, which integrates all signals as a function of delay relative to the 2 Hz trigger pulse. The first peak is induced by the photons, which are emitted from the plasma and the second peak is the actual pulsed atomic oxygen beam with broader distribution.





Scheme of AO interaction with the lipstick 3D microscopy of Boho lipstick cleaning in progress

Conclusions

In the reconstruction of the NASA Warhol treatment, contemporary lipsticks were exposed to AO under low-pressure conditions, which made lipsticks appear lighter but did not remove them. Lipsticks contained red iron oxides, which are not affected by AO. However, the AO role was essential, as it converted organic compounds in the lipstick into volatile byproducts (CO, CO_2, H_2O vapor), leaving a dry powdery residuum on the surface. This enabled the dry removal of the residual powder using soft natural rubber in a second step, repeating NASA's methodology. The colorimetric analysis confirmed highly effective recovery, and FTIR-ATR did not identify molecular changes in the substrate after cleaning. The issue of slow treatment (54.9 h) can be resolved by using atmospheric AO technology in development by the MOXY project), which reduces the treatment time from multiple hours to minutes and seconds. AO interactions with art materials are yet to be understood. Moxy is venturing into new territory and must address many questions to which there are no answers yet. But such is the path for innovation that is heading towards something transformative.

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Mock-ups were investigated with an array of techniques to obtain an initial assessment of the effects of AO exposure: spectrocolorimetry and reflectance spectroscopy were used to assess colour differences and changes in the spectral features; Optical and 3D digital microscopy to assess surface morphology, FTIR-ATR, to gain insights into molecular effects. Time of flight mass spectrometry (TOF-MS) to the quality and energy distribution of the pulsed beam during the AO exposure. XPS, SEM findings could not be discussed here becauue of the limited space.

References: [1] https://www.interviewmagazine.com/culture/paloma-picasso-the-diamond-dove-andy-warhol [2] Halford, B. (2005) Oxygen Gives New Life To Art in Chemical & Engineering News ISSN 0009-23470 [3] Banks, B., Rutledge, S., Karla, M., Norris, M., Real, W., Haytas, C. 1999. Use of an Atmospheric Atomic Oxygen Beam for Restoration of Defaced Paintings, in Proceedings of the 12th ICOM-CC Meeting, 1999, NASA/TM-1999-20941 [4] Green Atmospheric Plasma Generated Monoatomic OXYgen Technology for Restoration of the Works of Art Art MOXY - 2022-2026. Grant agreement ID: 101061336. https://cordis.europa.eu/project/id/101061336. (5) T. Markevicius, I. Bonaduce,A. Nikiforov, N. Olsson, P. Rasmussen, A. Suliga, Nan Yang, Geert van der Snickt, Silvia Pizzimenti, Catarina Pires (2023) Nascent oxygen: green atmospheric plasma-generated monoatomic oxygen for contactless and chemicals-free cleaning of works of art. ICOM-CC2023. Under review (6) Miller, N.J., Druzik, J.R. 2012. Demonstration Assessment of Light-Emitting Diode (LED) Retrofit Lamps at an Exhibit of 19th Century Photography at the Getty Museum (No. PNNL-21225). In Technical Report, Pacific Northwest National Lab.Richland, WA, USA.

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