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EO for Cultural and Natural Heritage Workshop 2024

15-16 October 2024 | ESA/ESRIN

From the Low Earth Orbit to Cultural Heritage and the Horizon Europe MOXY Project:

Tailored Cold Plasma-Generated Atomic Oxygen for Non-Contact Cleaning Sensitive Works of Art

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1: Ghent University, Belgium, 2: Nina Olsson Art Conservation, USA; 3: University of Amsterdam, The Netherlands; 4: Science Applications International Corp. at NASA Glenn Research, USA; 5: NASA Glenn Research Centre, USA; 6: University of Pisa, Italy; 7: National Gallery of Denmark, Denmark; 8: ICOMOS Lietuva, Lithuania

GREEN CLUSTER FOR SCIENCE AND CONSERVATION RESEARCH

MOXY Green Atmospheric Plasma-Generated Monoatomic Oxygen Technology for Restoration of Works of Art

Funded by the European Union

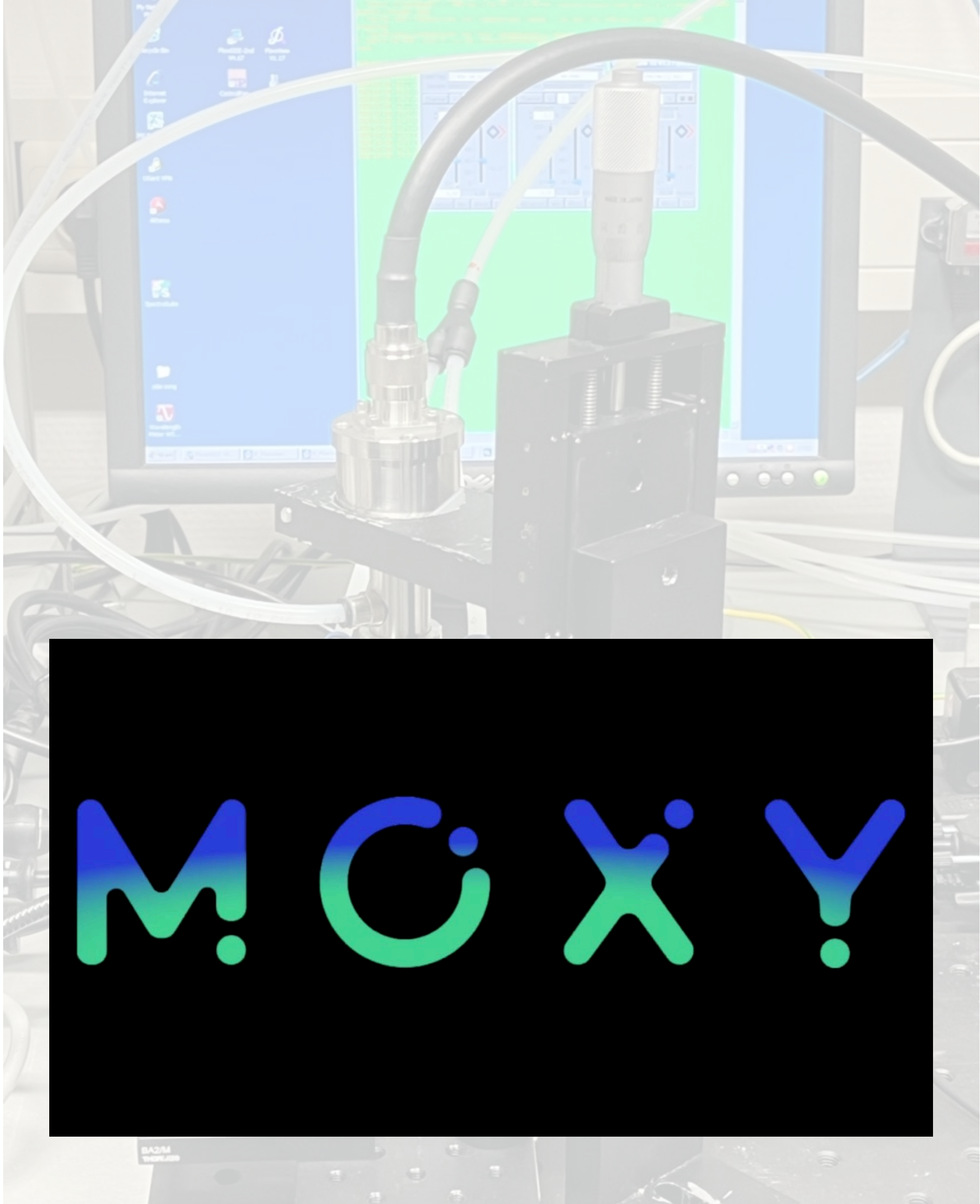
Origins of Atmospheric Atomic Oxygen Cleaning

Bruce A. Banks
Science Applications International Corp. at NASA Glenn Research Center
and
Sharon K.R. Miller
NASA Glenn Research Center

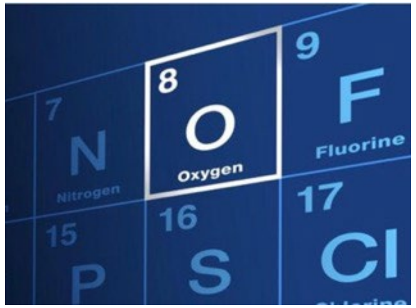
"The Moxy project stands alone in the world as it embarks upon the development of new and non-traditional methods of art restoration that may enable cleaning of artworks not previously possible through the use of atomic oxygen."

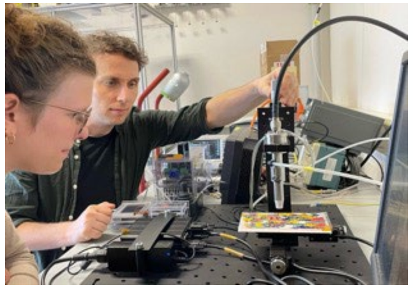
NASA scientists Bruce Banks and Sharon Miller pioneered AO in art conservation.
They opened the MOXY project kick-off meeting on November 1, 2022,
via a virtual bridge between NASA Glenn Center and Ghent University.

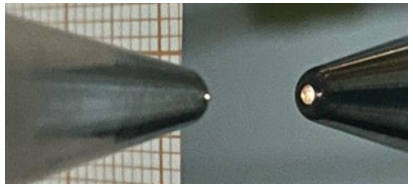
Bruce and Sharon are members of the Scientific Advisory Board (SAB) of the MOXY project.

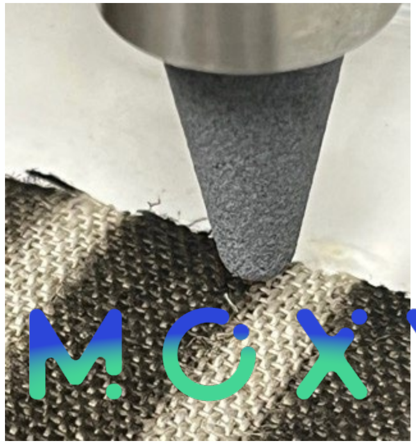


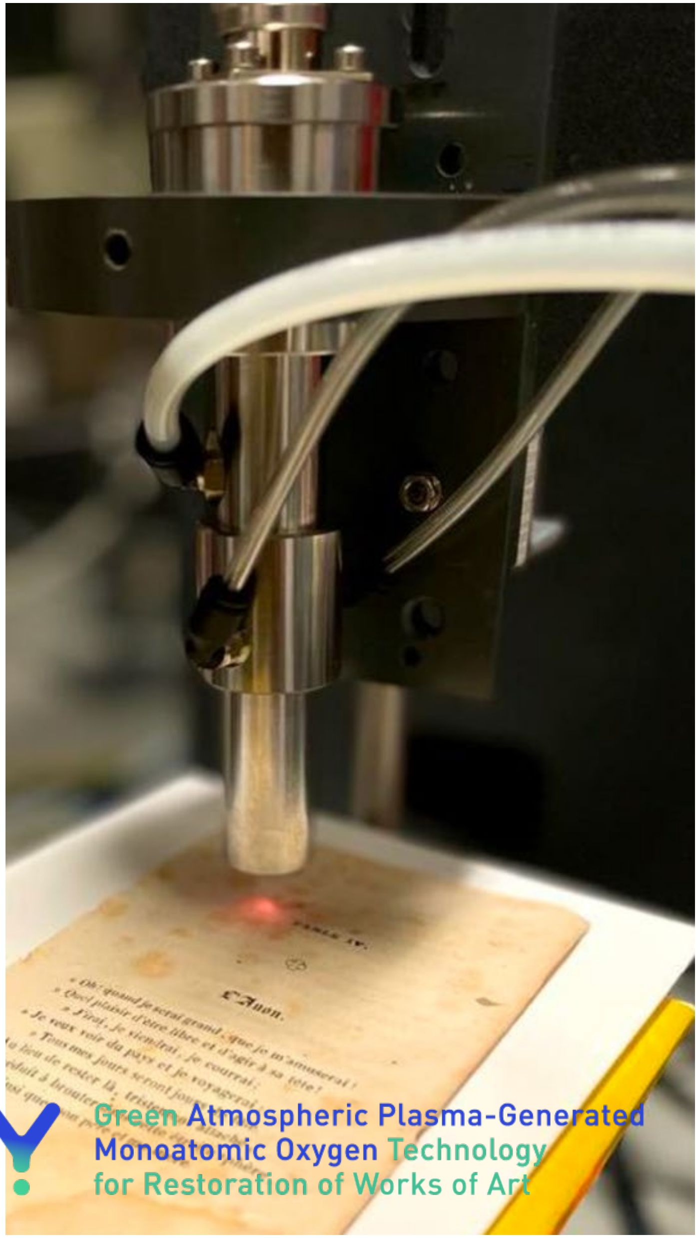
- The MOXY project
- Research consortium and researchers
- Challenges of cleaning carbon-based contaminants
- Atomic oxygen in outer space and rocket science
- Atomic oxygen origins in conservation
- The new atmospheric AO concept
- Investigating and tailoring AO for conservation
- Substrates and contaminants
- Investigating AO effects











MOXY esa

Funded by the European Union

Objectives

O1	Green AO technology elicitation
O2	Research and development of an atmospheric AO device
O3	Investigate AO generation and transport to the substrate
O4	Investigate AO interactions with contaminants and art materials
O5	Test, characterize and tailor AO for conservation
O6	Investigate and develop an AO sensor for conservation
O7	Road-map AO technology, assess environmental impact via LCA
O8	Communicate, demonstrate and disseminate the results

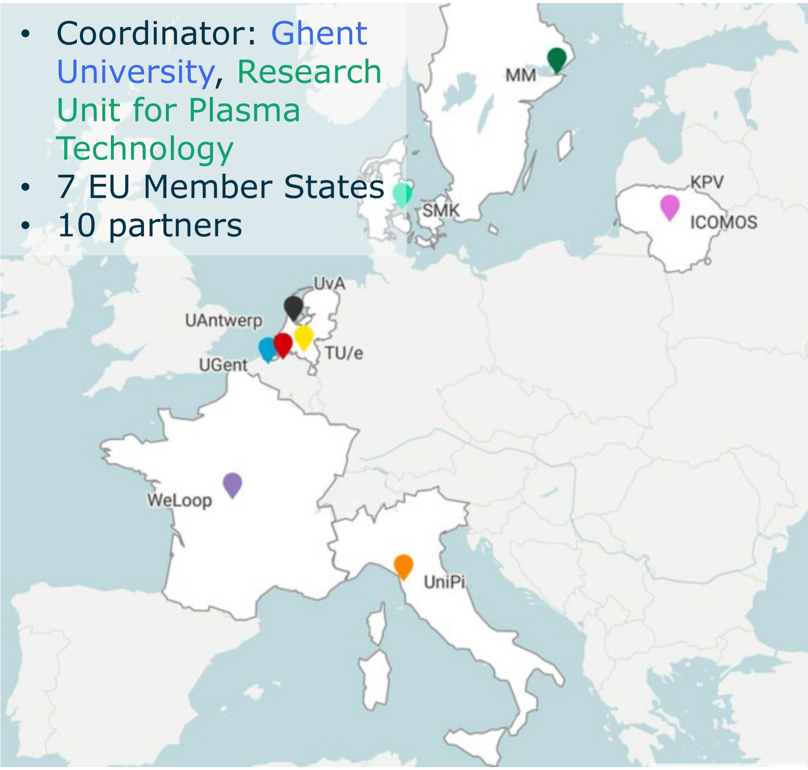
www.moxyproject.eu

moxy.project

Horizon Europe
Grant agreement 101061336
Start date: Nov. 1, 2022
Duration: 48 months

MOXY Green Atmospheric Plasma-Generated Monoatomic Oxygen Technology for Restoration of Works of Art

- Coordinator: Ghent University, Research Unit for Plasma Technology
- 7 EU Member States
- 10 partners



MOXY researchers at the kick-off meeting, 07/11/2022, Ghent University

University of Ghent, (Ghent, BE), **University of Amsterdam** (Amsterdam NL), **Technical University Eindhoven** (Eindhoven NL), **University of Antwerp** (Antwerp, BE), **WeLoop** (Lambersart, FR), **University of Pisa** (Pisa, IT), **ICOMOS Lietuva** (Vilnius, LT), **Modernamuseet** (Stockholm, SE), **KPV** (Vilnius, LT), **National Gallery of Denmark** (Copenhagen, DK).

Formation of the
Green Cluster for Science and Conservation Research
Horizon Europe | Type of action: RIA | Topic: CL2-2021-HERITAGE-01-01

go green — Coordinated by the **University of Amsterdam, 13 partners**

MOXY — Coordinated by the **RUPT, University of Ghent,10 partners**

GREENART — Coordinated by the **CSGI, University of Florence, 30 partners**

GREEN CLUSTER FOR SCIENCE AND CONSERVATION RESEARCH

53 organizations

Research teams

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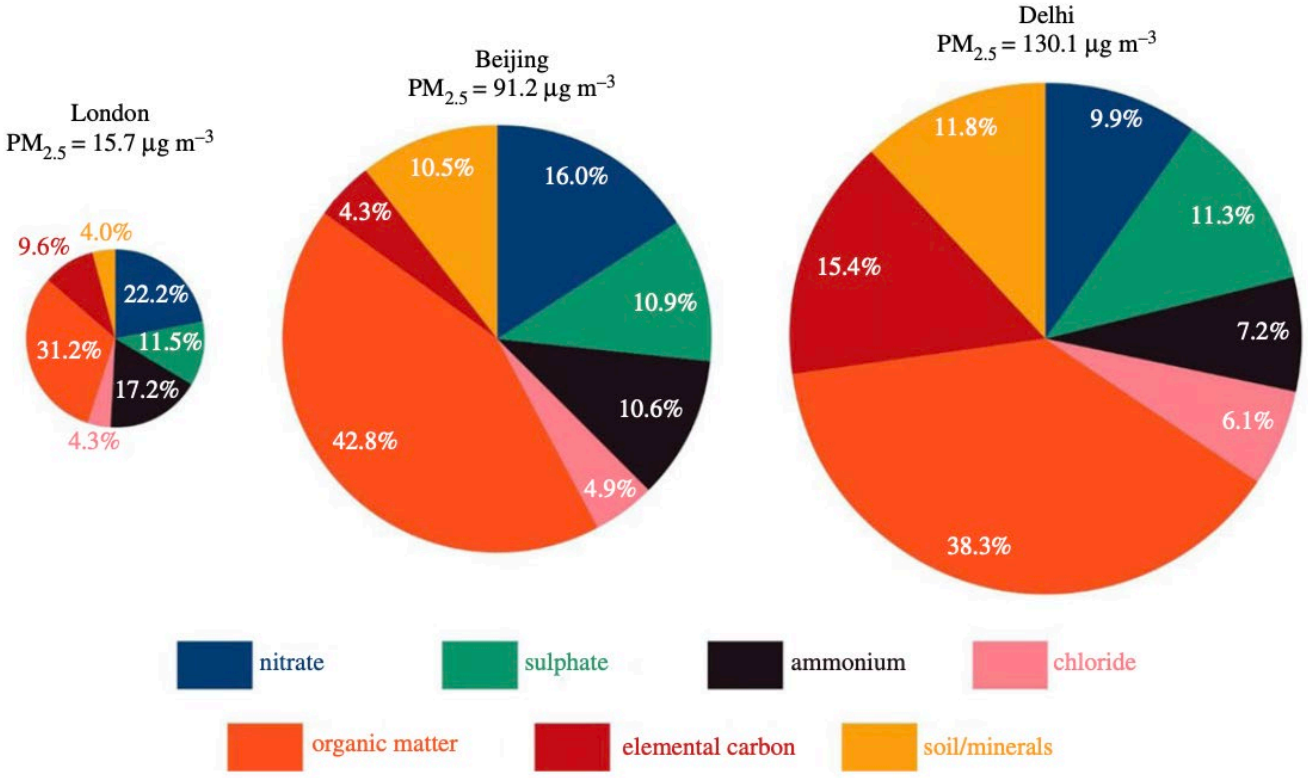
Challenges cleaning carbon-based contaminants

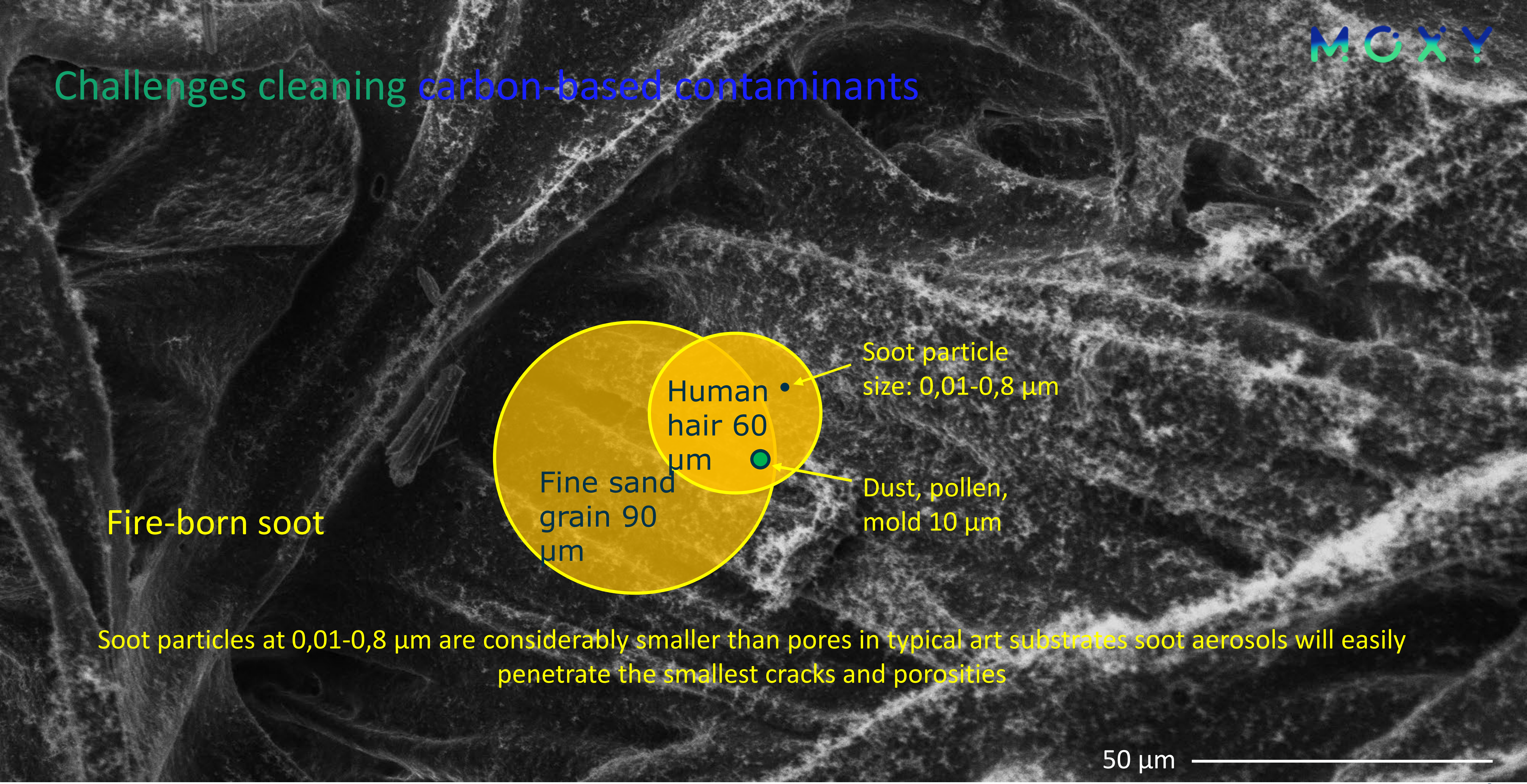
Carbon-based contaminants constitute a significant portion of soiling materials: soot, organic carbons, fine particulate matter, tobacco smoke, tar, handprints, bacteria, fungi, conservation materials, biocides, defacement materials, material degradation products



Major chemical component composition of PM2.5 in London, Beijing and Delhi*

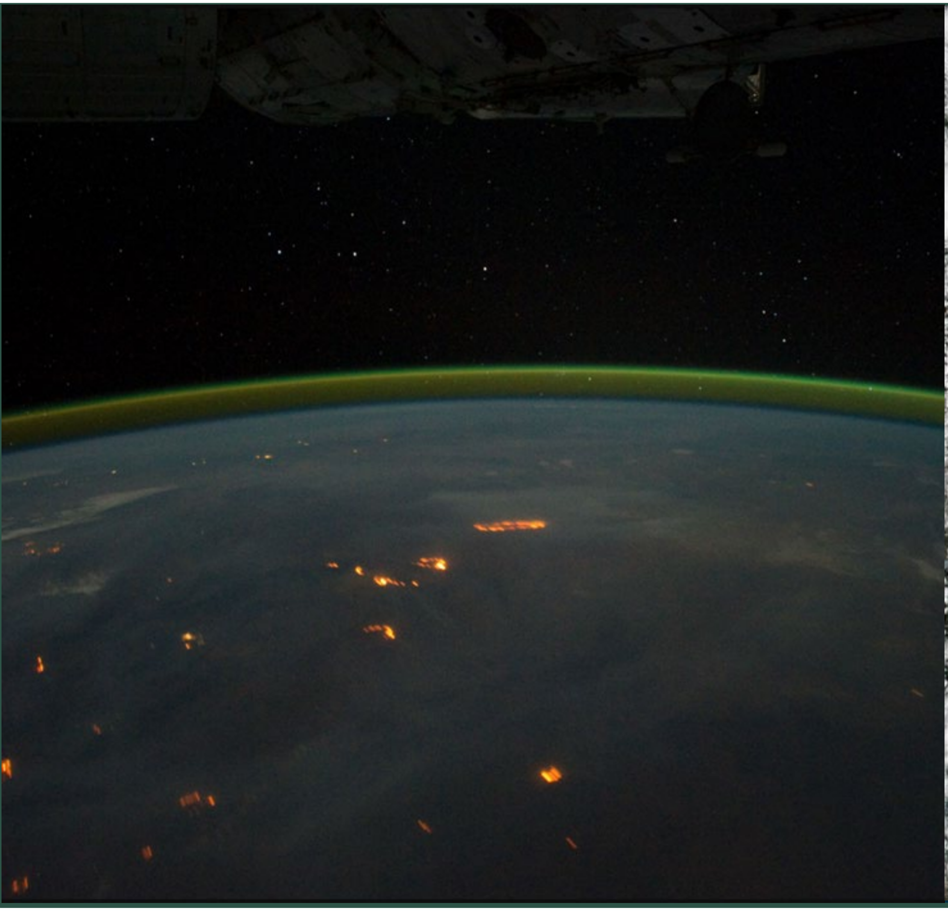
*Harrison RM. 2020 Airborne particulate matter. Phil. Trans. R. Soc. A 378: 20190319 http://dx.doi.org/10.1098/rsta.2019.0319

Challenges cleaning carbon-based contaminants



Soot particles at 0,01-0,8 µm are considerably smaller than pores in typical art substrates soot aerosols will easily penetrate the smallest cracks and porosities

Cultural Heritage and Climate Change



2011 NASA image of wildfires on Earth from space satellite.

August 10, 2024 NASA image of wildfires in BC, Canada

I-5 Southbound Salem OR, August 2021

Challenges cleaning carbon-based contaminants

Sustainable preservation of tangible cultural heritage is inherently linked to the UN's Sustainability Development Goals (SDG 11, **Target 11.4** *Strengthen efforts to protect and safeguard the world's cultural and natural heritage.*)

The conservation field currently lacks empowering green technologies, especially in cleaning treatments.

Conservators, equipped only with contact methods encounter sensitive surfaces where soiling cannot be removed at all.

Contact cleaning is particularly problematic with sensitive object surfaces (SOS), such as porous mineral materials (plaster, alabaster), friable media (pastels, modern paints), woven and nonwoven materials (unprimed canvases, textiles, paper), animal-sourced materials (feathers, silk, ivory, bone), plastics, and modern media, which can be exacerbated challenging geometries and topographies.

The available "wet" and "dry" contact cleaning methods used to remove CBC risk abrading the surface and transporting contaminants into the porous substrate, displacing loose fragments, swelling and shrinking the paint, and facilitating the migration of leachable components.

Atomic oxygen (AO) origins in NASA and ESA research: erosion effects on spacecraft materials in Low Earth Orbit (LEO)

MOXY

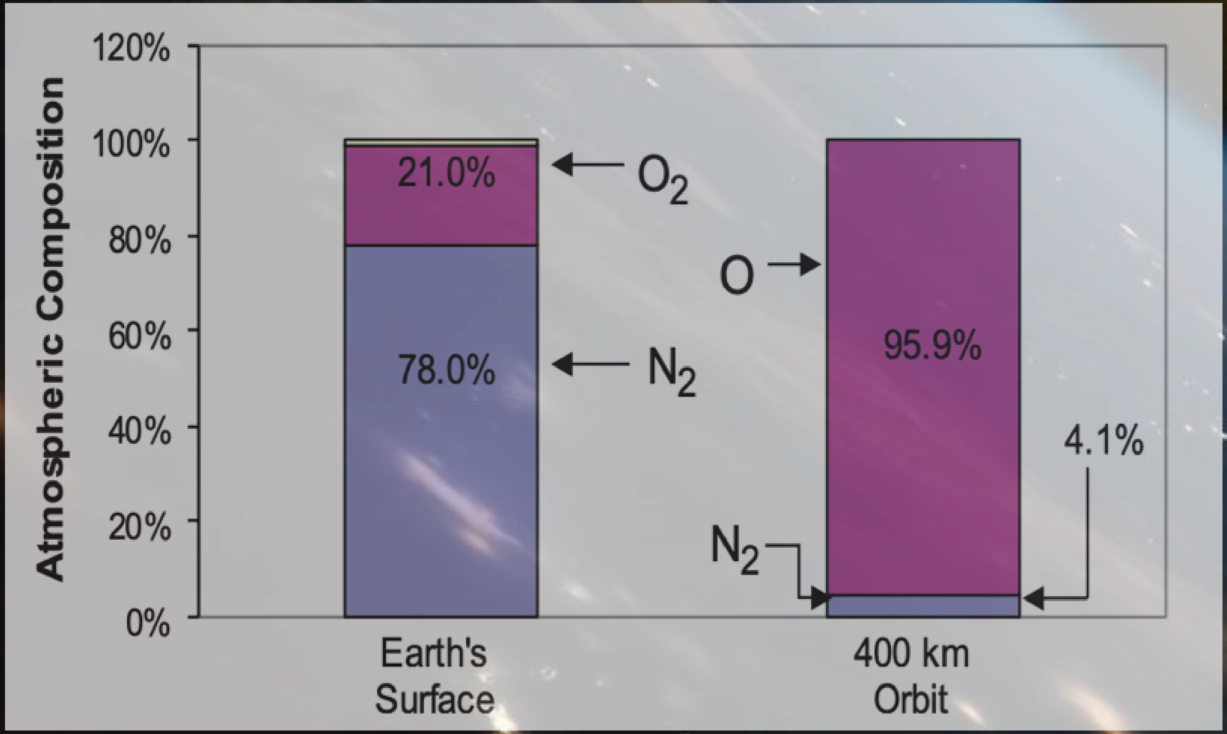
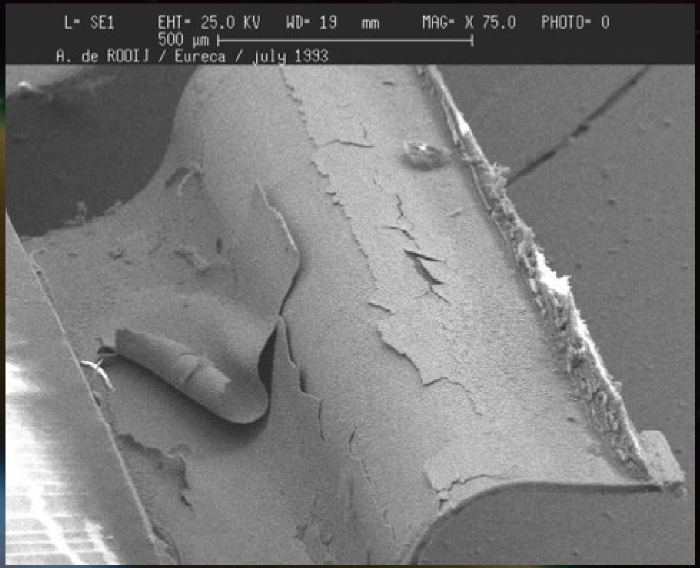


Image: Sharon Miller, NASA



Silver interconnector 25 µm retrieved from European Retrievable Carrier EURECA. Oxidized silver is flaked off and exposes the underlying fresh material, which is oxidized again. Photo: ESA. Rooij, Antonius. (2010). Corrosion in Space. doi: 10.1002/9780470686652.eae242.

AO is a space environment element naturally present in the LEO: low Earth Orbit (80 - 1000 km) and is extremely short-lived on the ground (a few milliseconds). In LEO, 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.

AO origins in NASA and ESA research: erosion effects on spacecraft materials

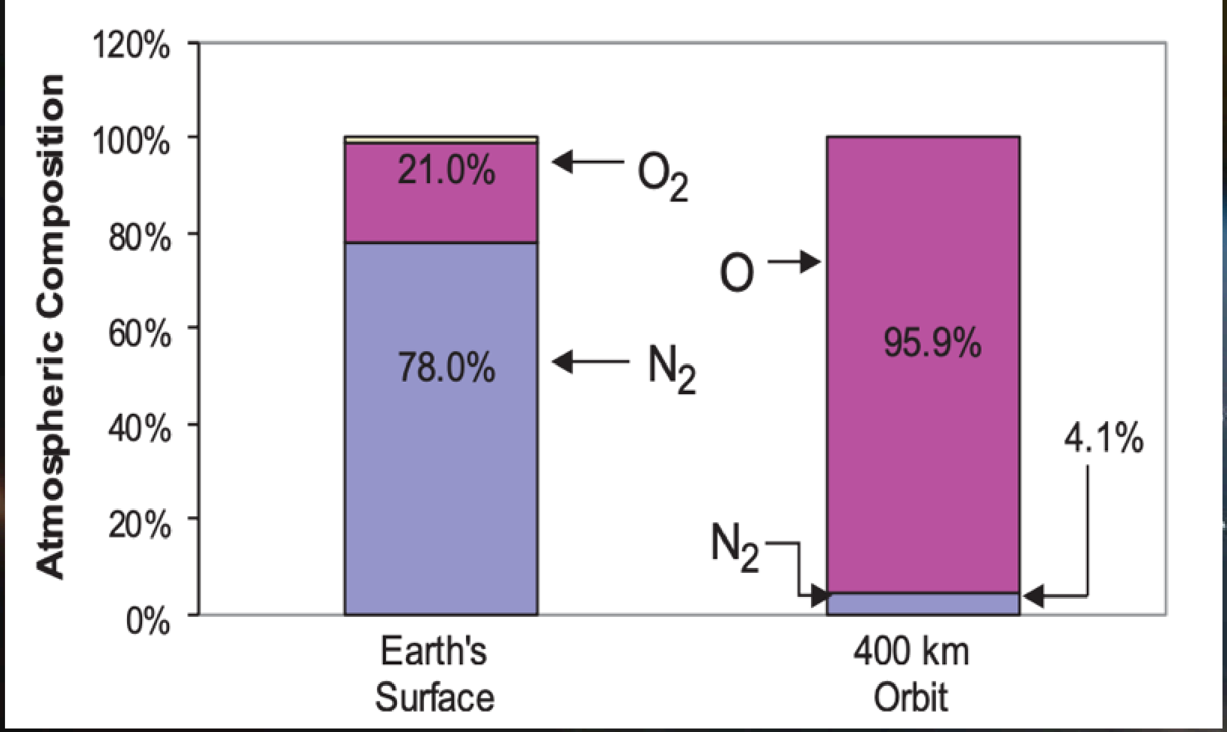
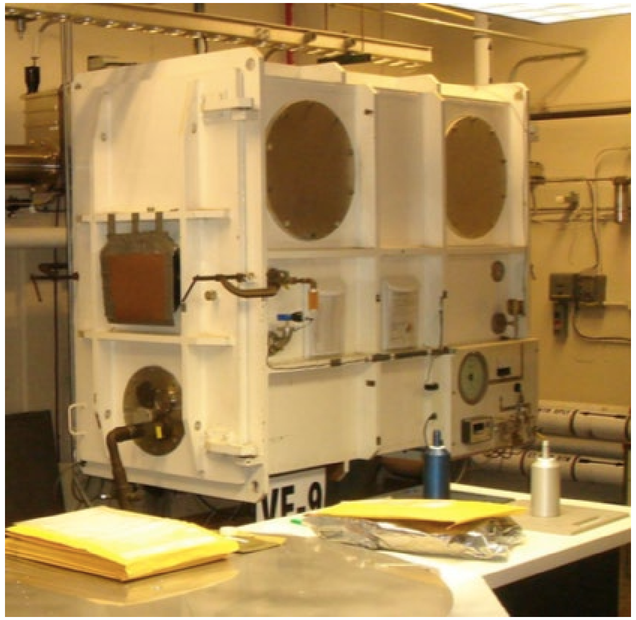


Image: Sharon Miller, NASA

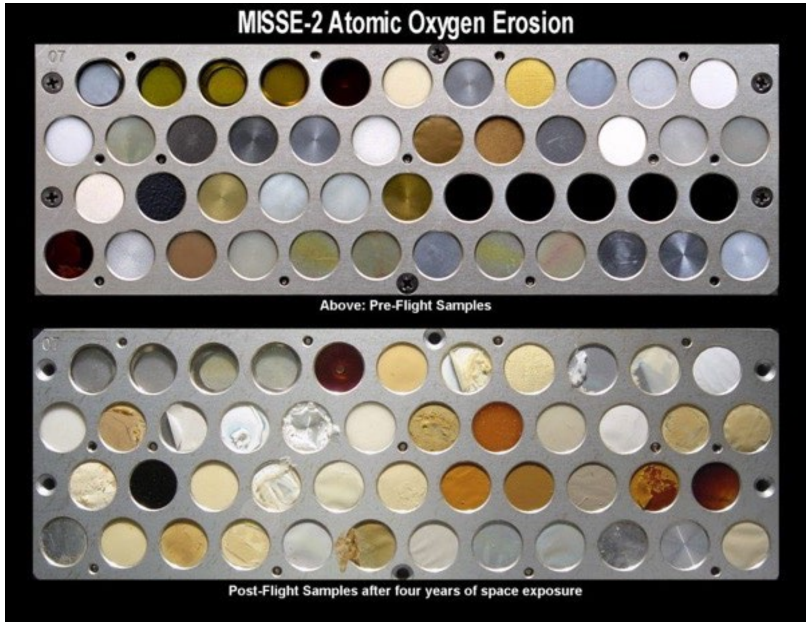
Species	Oxidation potential eV
Fluorine F	3.03
Hydroxyl radical OH	2.80
Atomic oxygen O	2.24
Ozone O_3	2.07
Hydrogen peroxide H_2O_2	1.78
Oxygen molecule O_2	1.26

AO is a space environment element in the region known as LEO: low Earth orbit (80 - 1000 km) and is extremely short-lived on the ground (a few milliseconds).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.

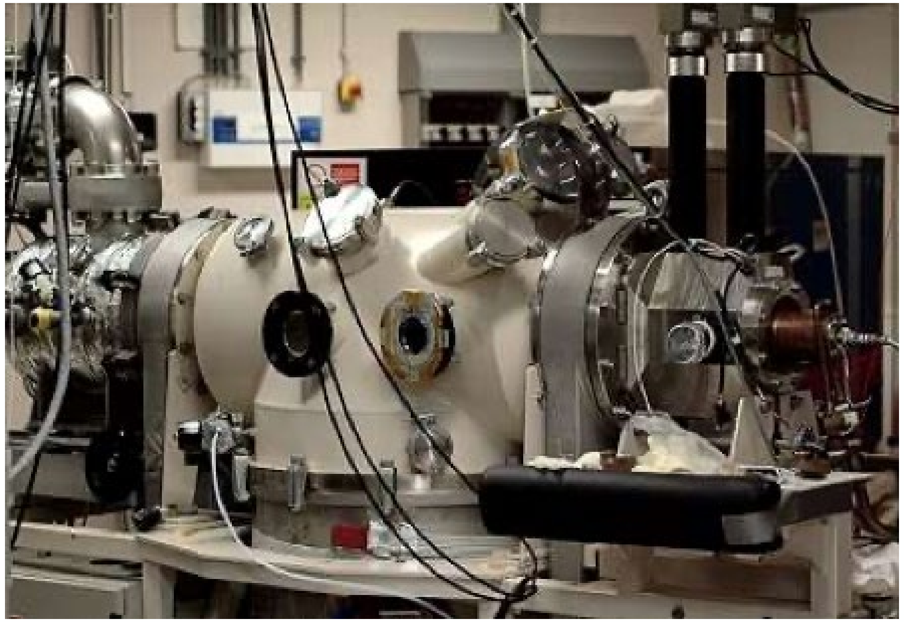
AO Origins in NASA and ESA research:
Low-pressure AO chambers for space environment simulation



NASA
The large Area Atomic Oxygen Exposure facility at NASA uses a 13.56 MHz RF generator to produce AO. Photo: NASA



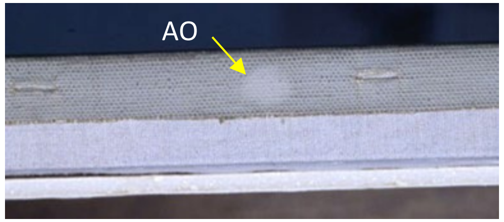
NASA
MISSE-2 AO testing in space environment. Photo: NASA



ESA
European Space Agency LEOX facility FAST-1TM AO Source by AMOS, Liege, Belgium. Photo: ESA

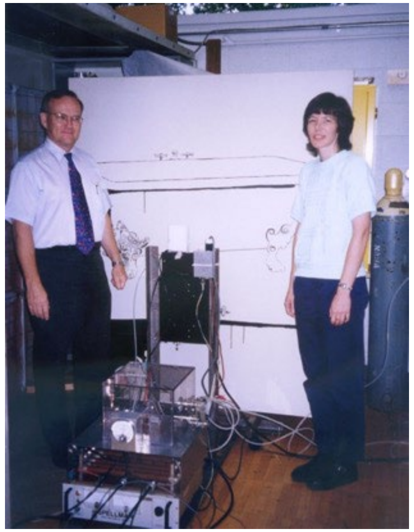
For the past thirty years, NASA and the European Space Agency (ESA) have investigated AO interactions with aerospace materials and developed AO simulation systems that typically work under low pressure and require sophisticated chambers.

Atmospheric AO origins in cultural heritage conservation:
Andy Warhol’s *The Bathtub* (1961) treatment by NASA, 1997

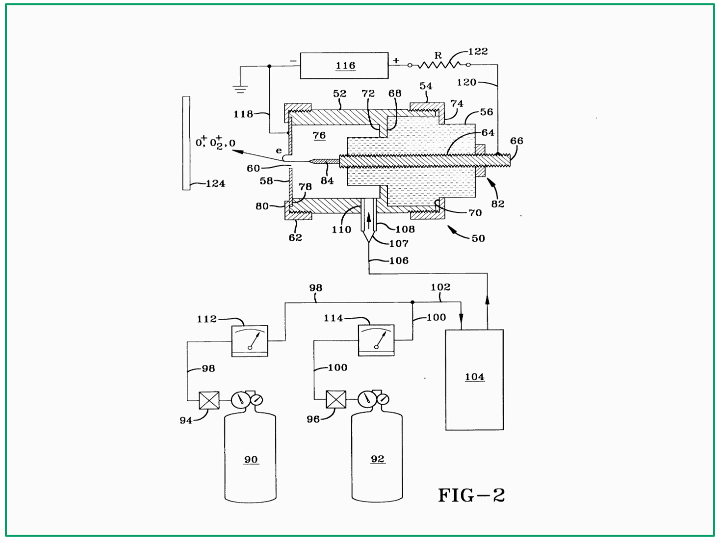


AO cleaning spot test: surface dirt

Lipstick mockups: half-cleaned and cleaning test spots

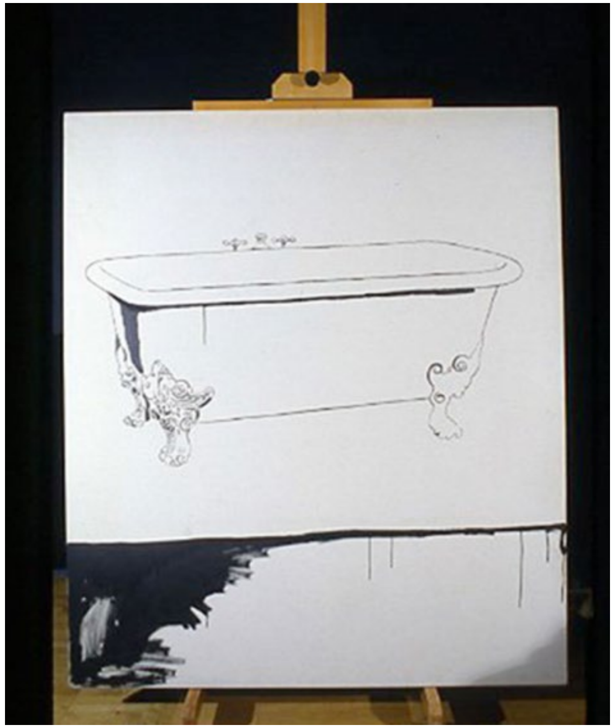


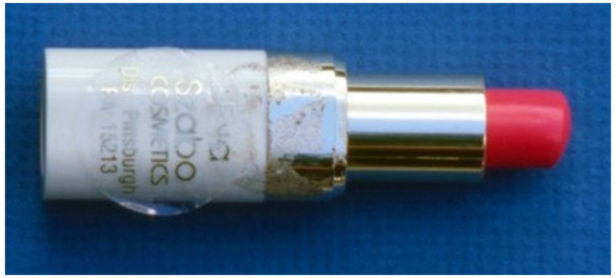
Bruce Banks and Sharon Miller during Andy Warhol's treatment at the Andy Warhol Museum. Image: NASA



NASA prototype system by B. Banks and S. Miller. The system used He (4,3 l/min) and O2 (0,1-0,2 l/min) and 7 kV and 5.8 mA DC arc. (21-42 W). Dissembled in 2019.

Atomic oxygen treatment: before and after
Images: The Andy Warhol Museum



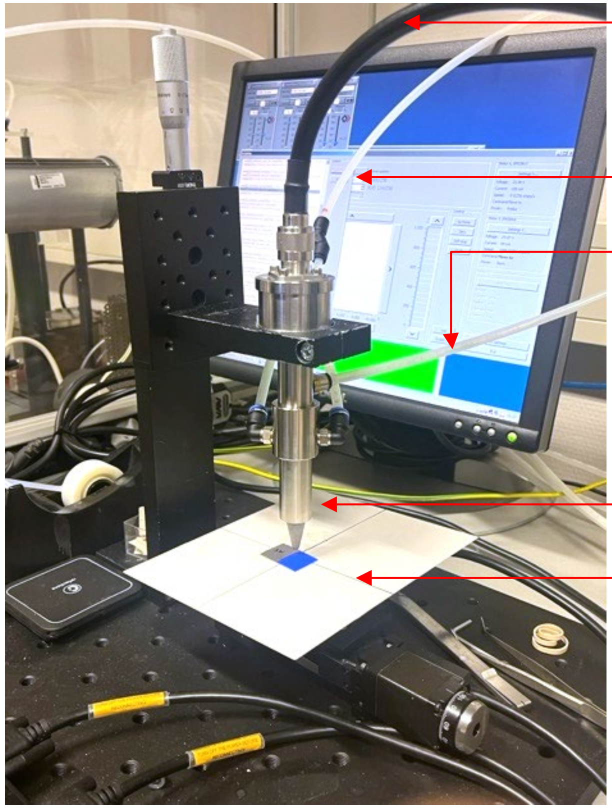


Andy Warhol's “The Bathtub” (1961) and Eva Szabo’s 302 Coral lipstick. Images: NASA and The Andy Warhol Museum

https://doi.org/10.5281/zenodo.10616579

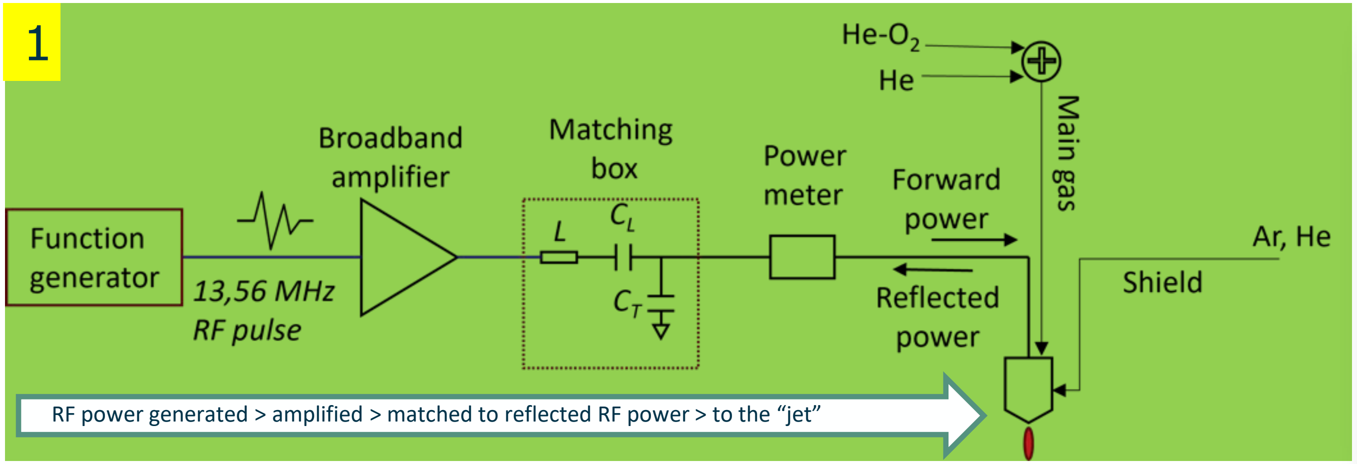
Tailoring AO for conservation:

Designing cold RF plasma generator at atmospheric pressure:

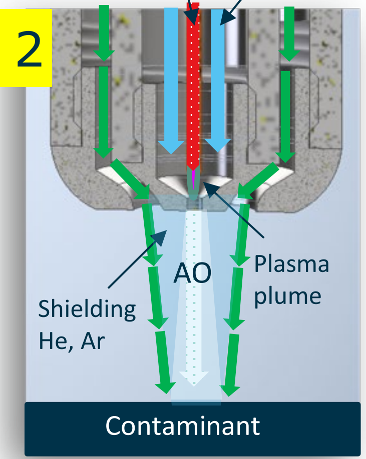


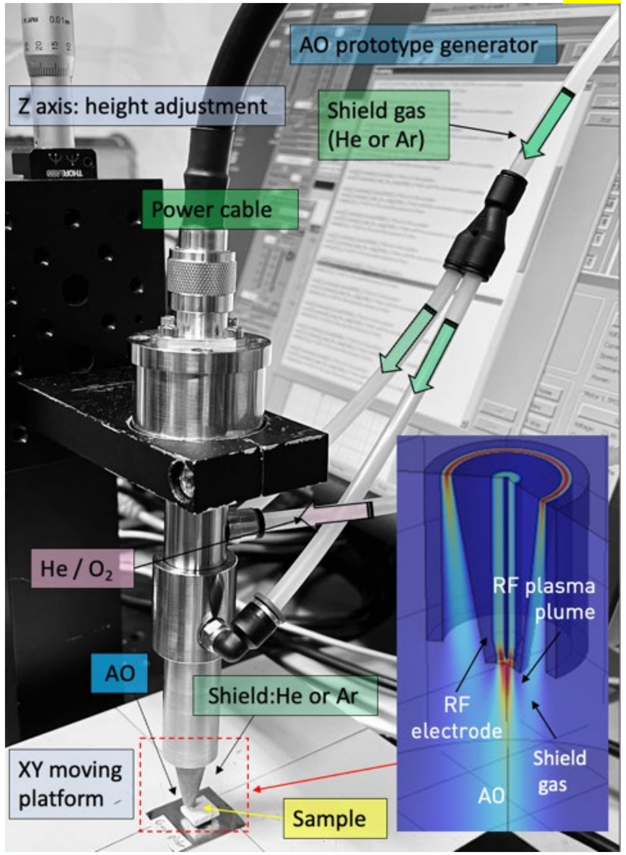
- RF power cable
- Main gas supply line: $He+O_2$ (flow controller)
- Shield gas supply line: Ar or He (flow controller)
- Cold plasma AO generator "jet"
- Function generator to produce RF power
- Broadband RF power amplifier
- Matching network to maintain RF power stable
- Moving stage XYZ
- Real-time probe for plasma parameters
- Computer, software for gas flow, plasma, stage

Tailoring AO: AO generation at atmospheric pressure

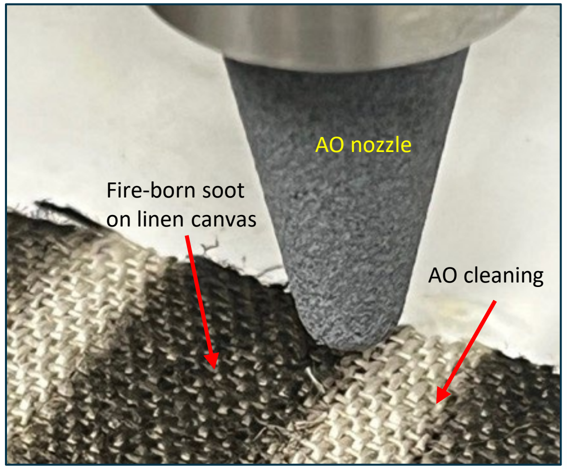


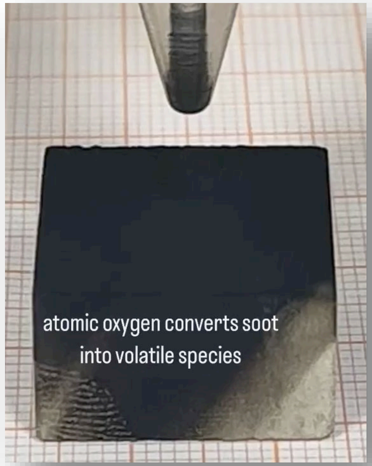
Flow chart of AO generation process and system component





Main elements of the AO generator and a cross-section of the nozzle with the main and shield gas flow dynamics





AO cleaning process on canvas and sandstone contaminated with soot

4

Radiofrequency RF: 13.56 MHz

Main gas: He / O_2(0.3%)

Shield gas: Ar or He

He/O_2 flow rate: 4 l/min

Shield gas (Ar, He) flow rate: 4l/min

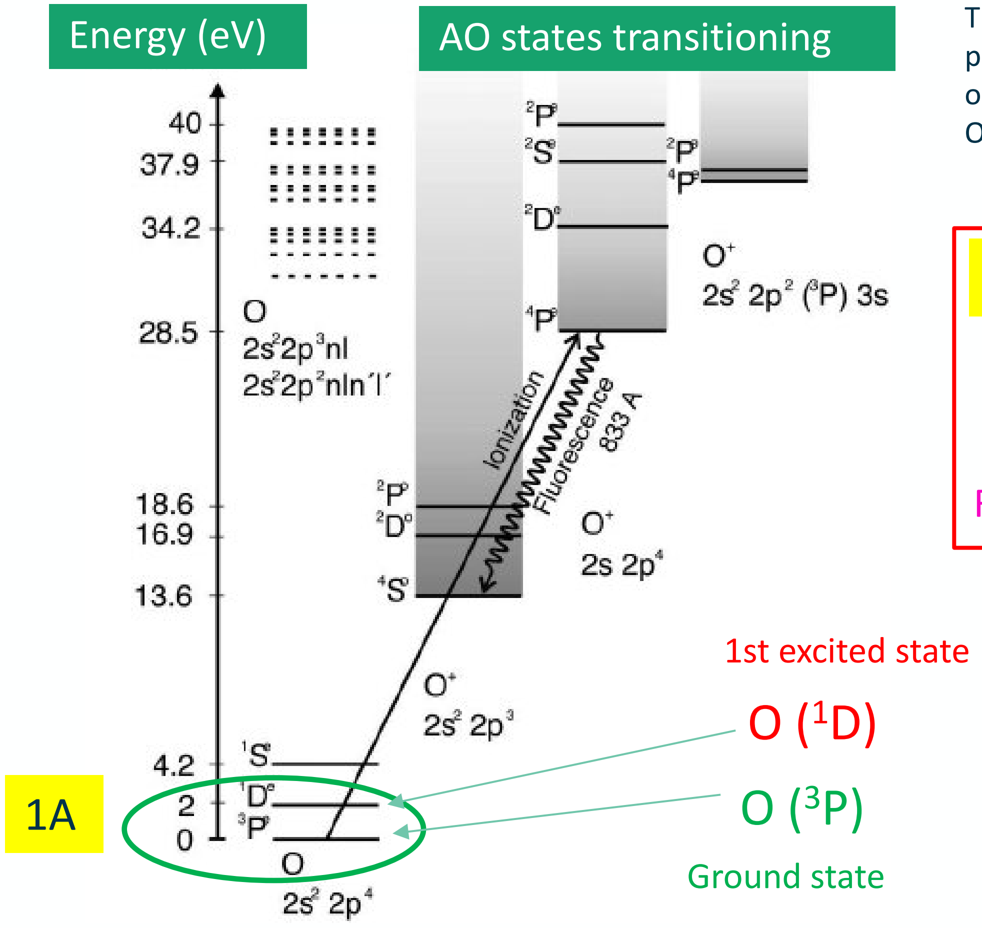
Plasma power: 1.5 -10 W (more possible)

Distance: 2-50 mm (typically 4 mm)

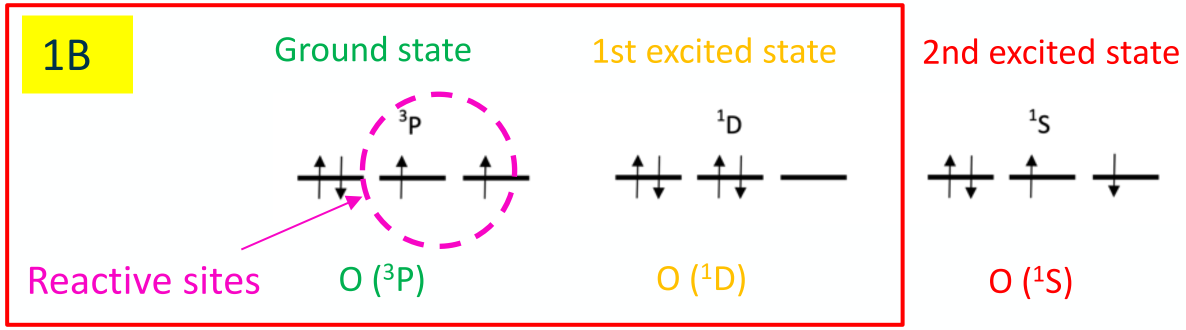
Temperature: 26-85C.

Main parameters of the MOXY AO generation system

Tailored AO at atmospheric pressure



The ground state O (³P) has 2 unpaired electrons (reactive sites). It is the lowest possible energy an O atom can have. Two reactive sites form bonds with other atoms or molecules, making AO reactive. The first excited state of AO is designated as the O(¹D) state. Configuration O(¹S) is the 2nd excited state.



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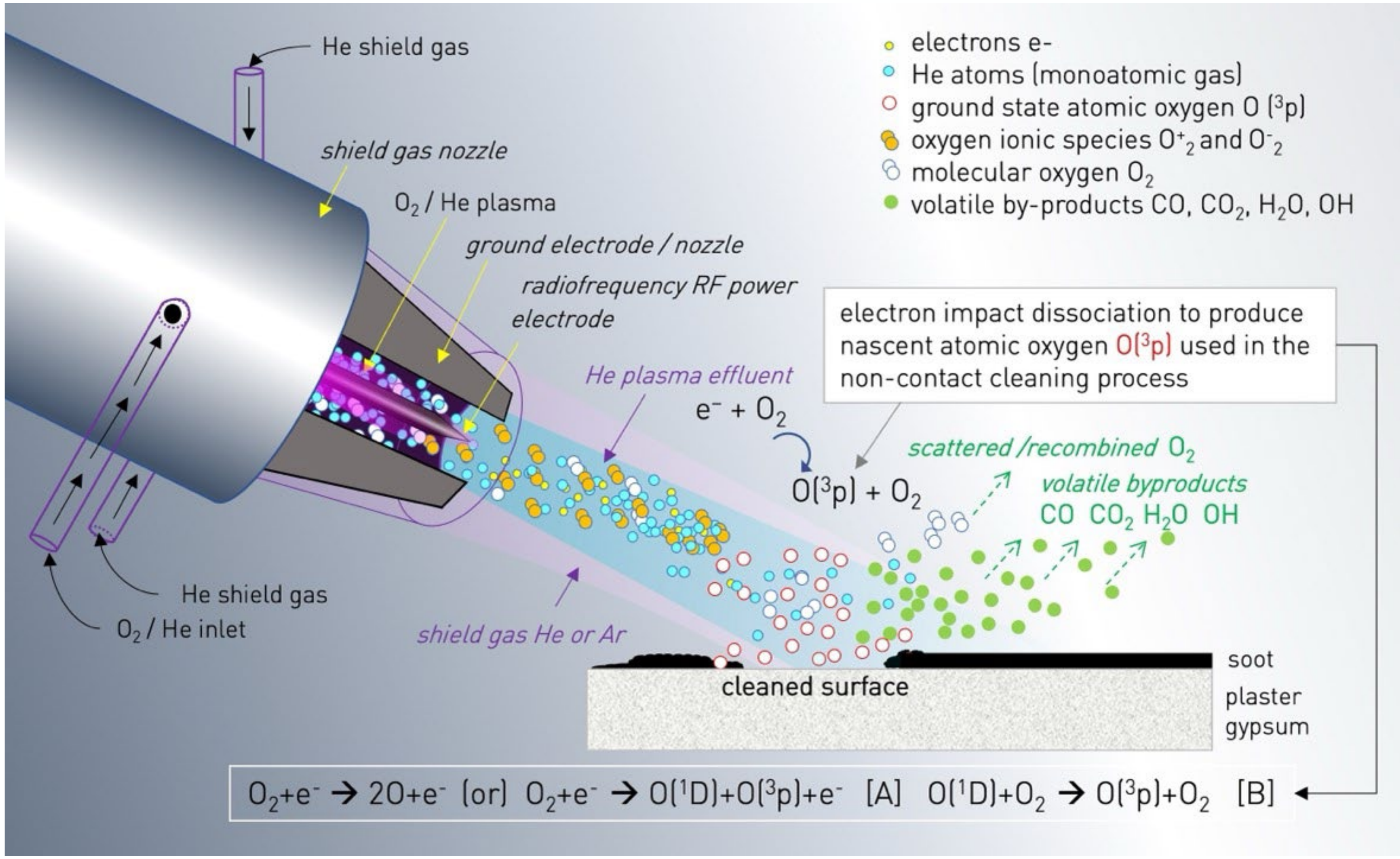
(A) $O_2 + e^- \rightarrow 2O + e^-$ (or) $O_2 + e- \rightarrow O(^1D) + O(^3P) + e^-$

(B) $O(^1D) + O_2 \rightarrow O(^3P) + O_2$

Typical contaminants affecting works of art are carbon-based materials, such as soot, hydrocarbons, and organic compounds, which AO converts into volatile species (CO, CO_2, water vapor). AO cleaning is limited to the surface, and AO needs to be produced and used instantaneously.

Testing AO on CH materials: AO at atmospheric pressure

Carbon-based contaminants constitute a significant portion of soiling materials: soot, organic carbons, fine particulate matter, tobacco smoke, tar, handprints, bacteria, fungi, past conservation materials, degradation products, biocides, foods, and vandalism materials.



Carbon

$C + O\,(^3P) > CO$ $\quad$ $CO + O\,(^3P) > CO_2$

$C + O\,(^1D) > CO$ $\quad$ $CO + O\,(^1D) > CO_2$

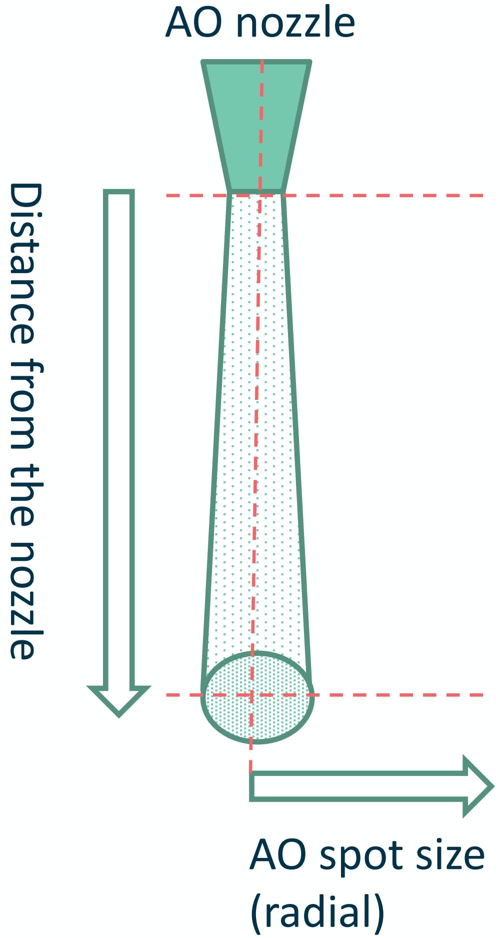
$C_{surface}$ (soot) + $O\,(^1D) > CO, CO_2$

Hydrocarbons

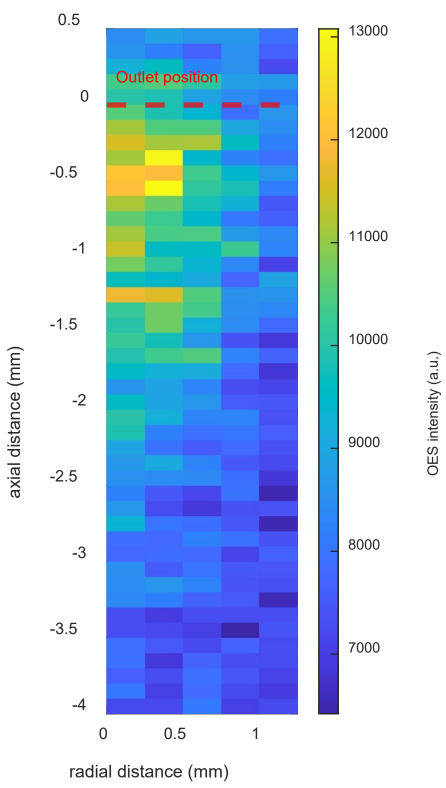
$C_xH_y + O\,(^3P) > CO, CO_2, H_2O$

AO reactions with carbon-based contaminants result in fragmentation and volatile products, enabling non-contact chemically selective cleaning at the surface

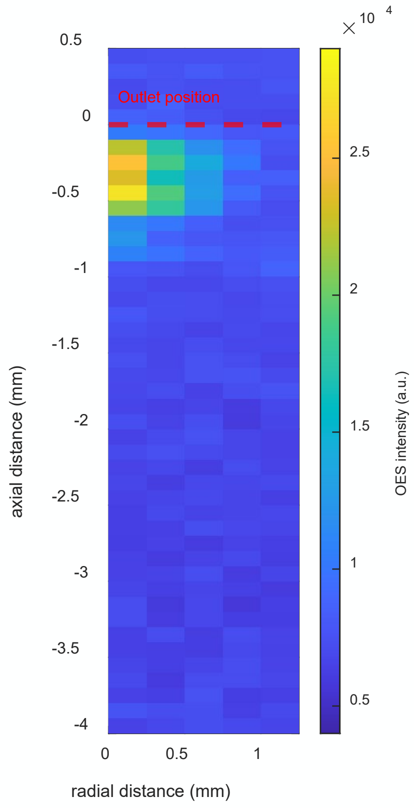
Radial and axial AO distribution: optical emission spectroscopy



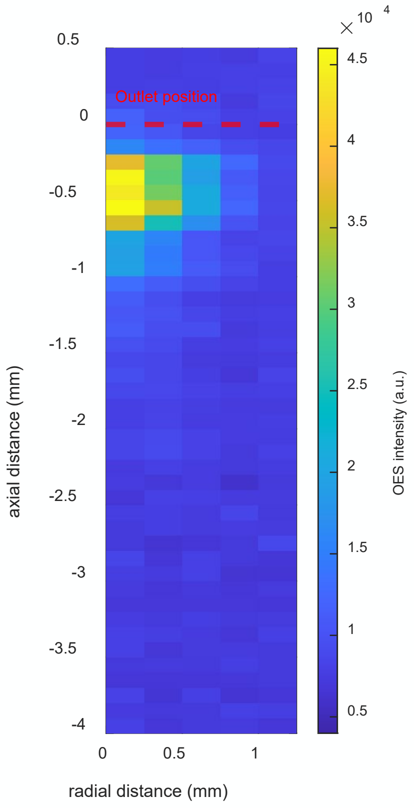
AO generated at: 4 l/min He/O_2 (0,3%) + 4 l/min Ar shielding, RF power 4 W



Excited N_2 at 337 nm

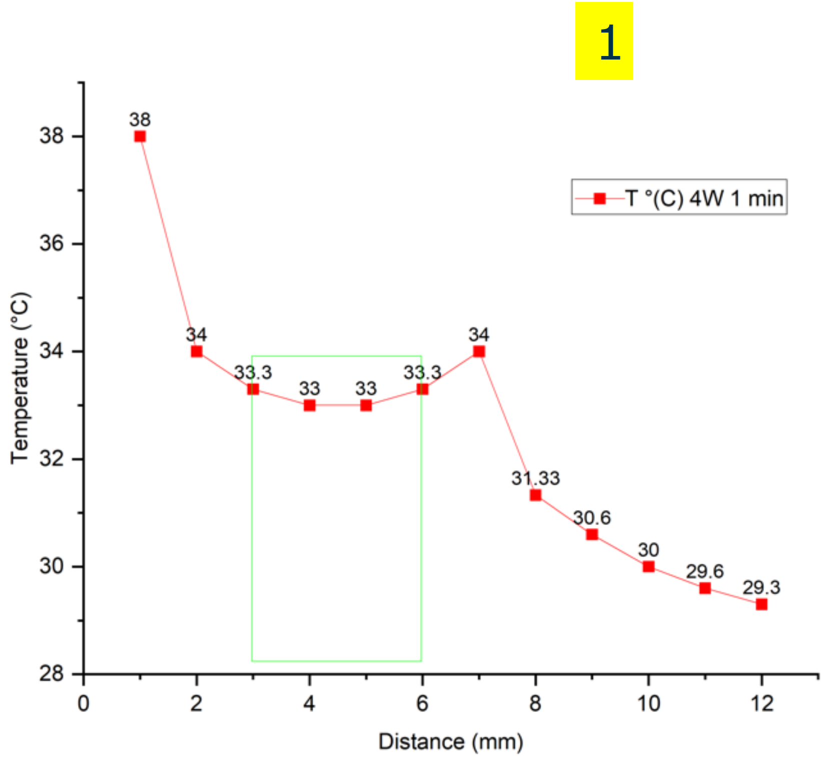


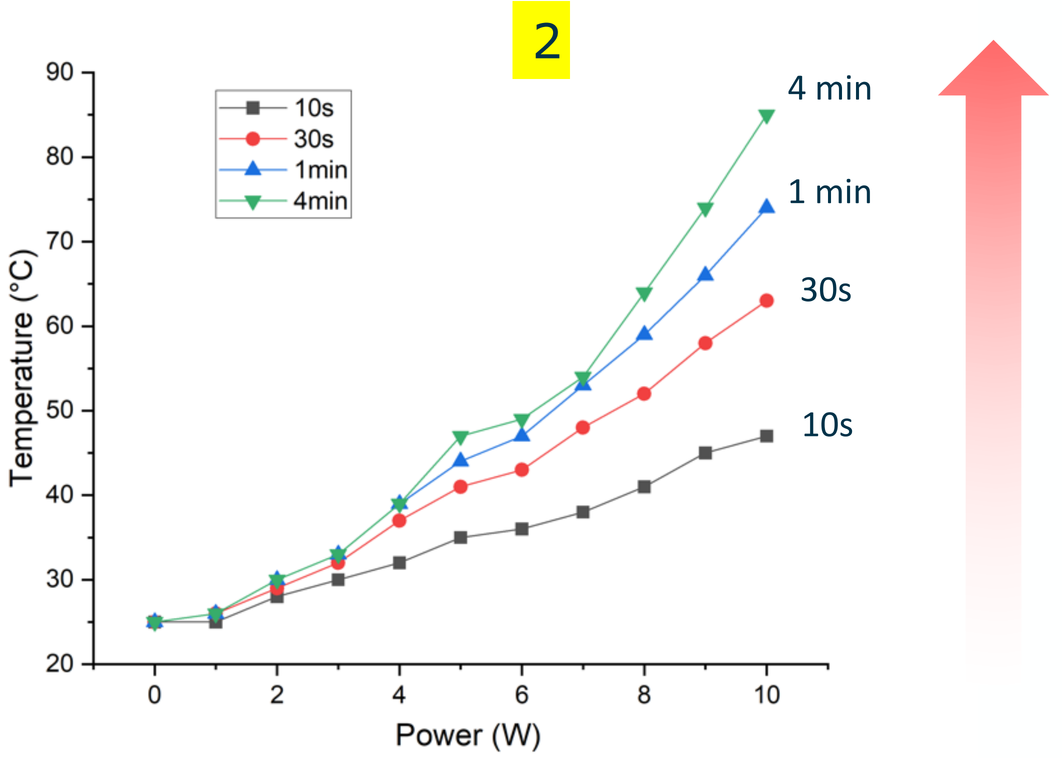
Excited He at 706 nm



Excited O (^1D) at 777 nm

Tailoring AO: optimizing treatment temperature

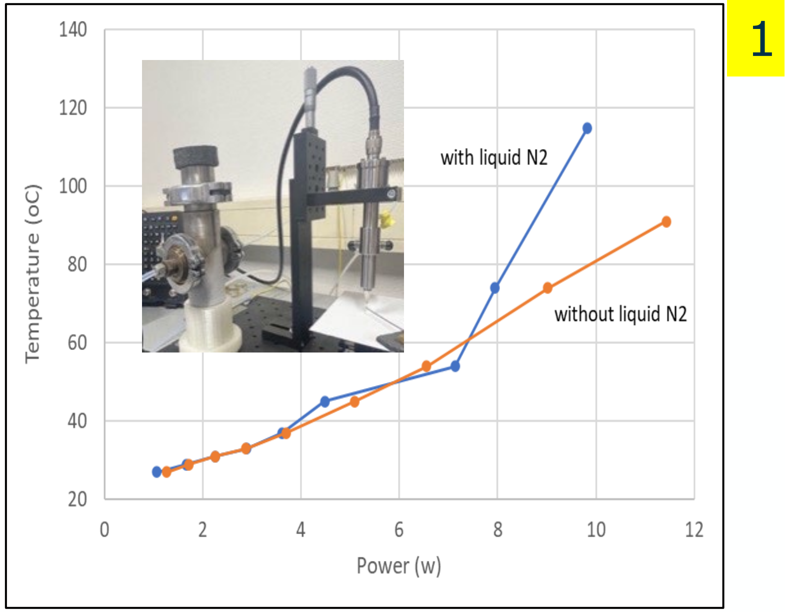




"Sweet spot" at 3-6 mm range

Short repeated exposures by moving sample > lower T

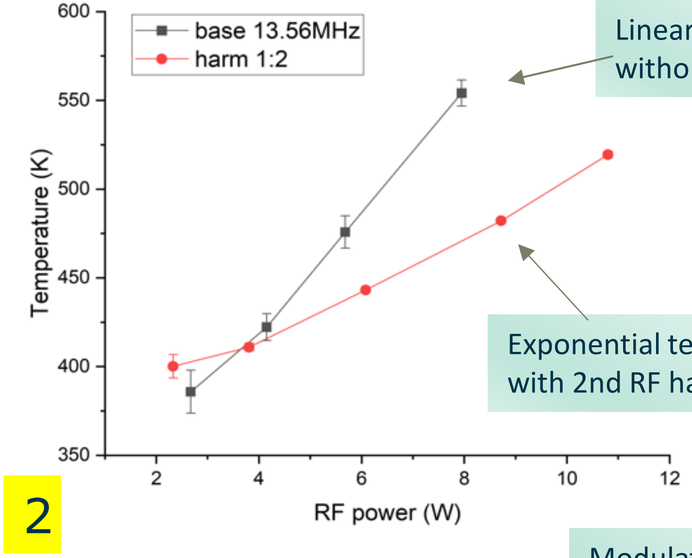
Tailoring AO temperature: plasma parameters

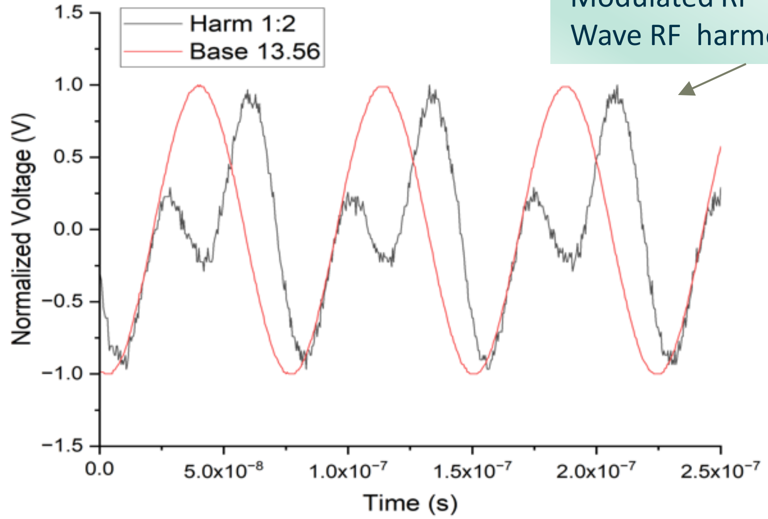


Pre-cooling He: temperature drop

Parameters tailoring temperature

- Power
- Gas-phase ratio
- 2nd harmonics
- Pre-cooling He
- Distance from the sample
- Sample moving speed (using XY stage)

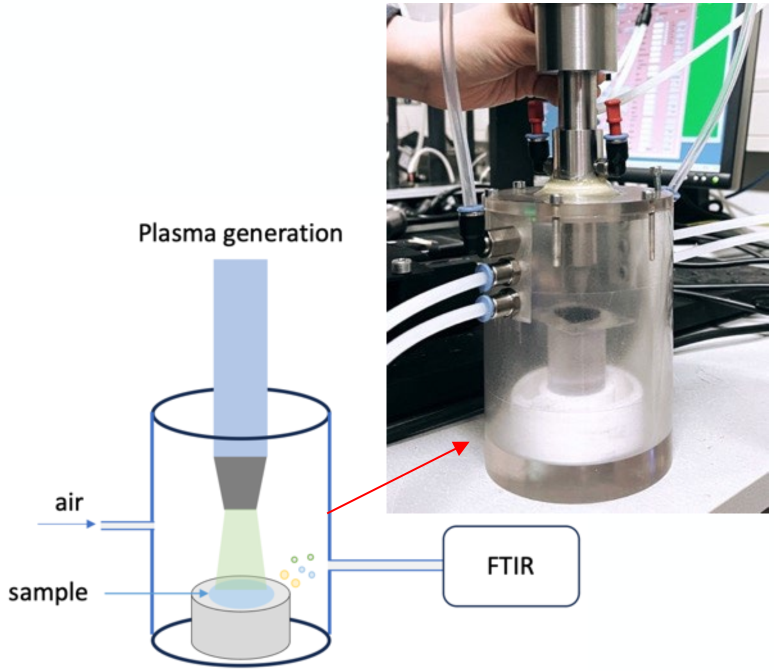




2^{nd} harmonic (sin wave) applied to RF plasma voltage

Tailoring AO for conservation: optimizing AO parameters

Time-dependant FTIR AO reactor and sample in a sealed container



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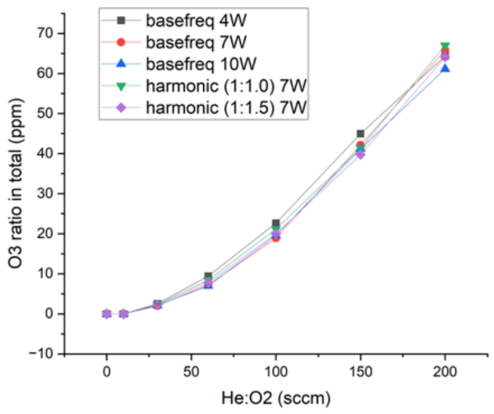


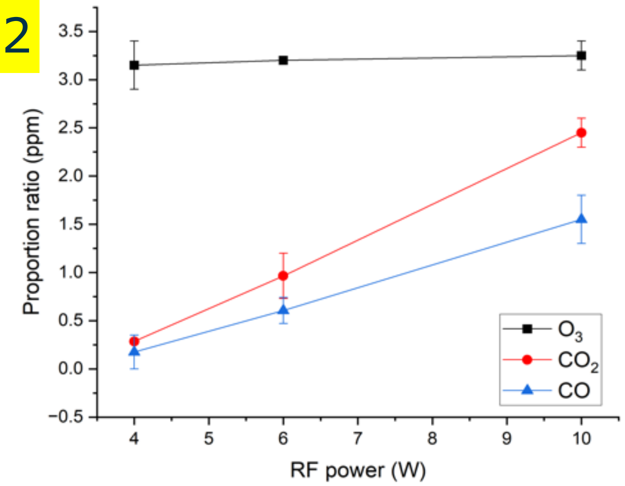
Optimimal 0,3% O_2

$O_3 > O_2$ ratio

Faster oxidation at higher power

no effect on O_3 generation

2

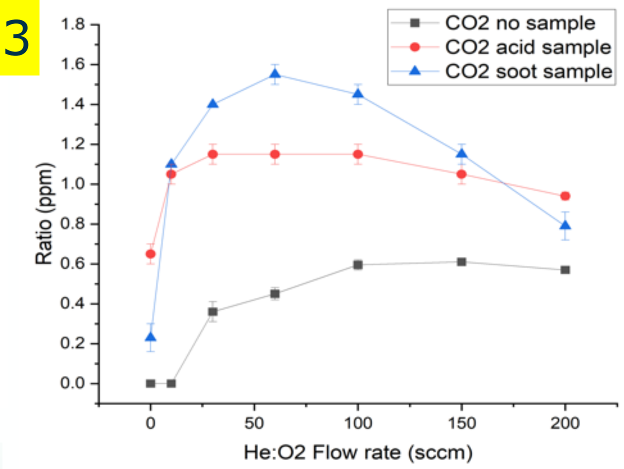


RF power effect on AO activity converting soot into CO and CO_2

Optimal 4-6W: 0,3-0.6 O_2

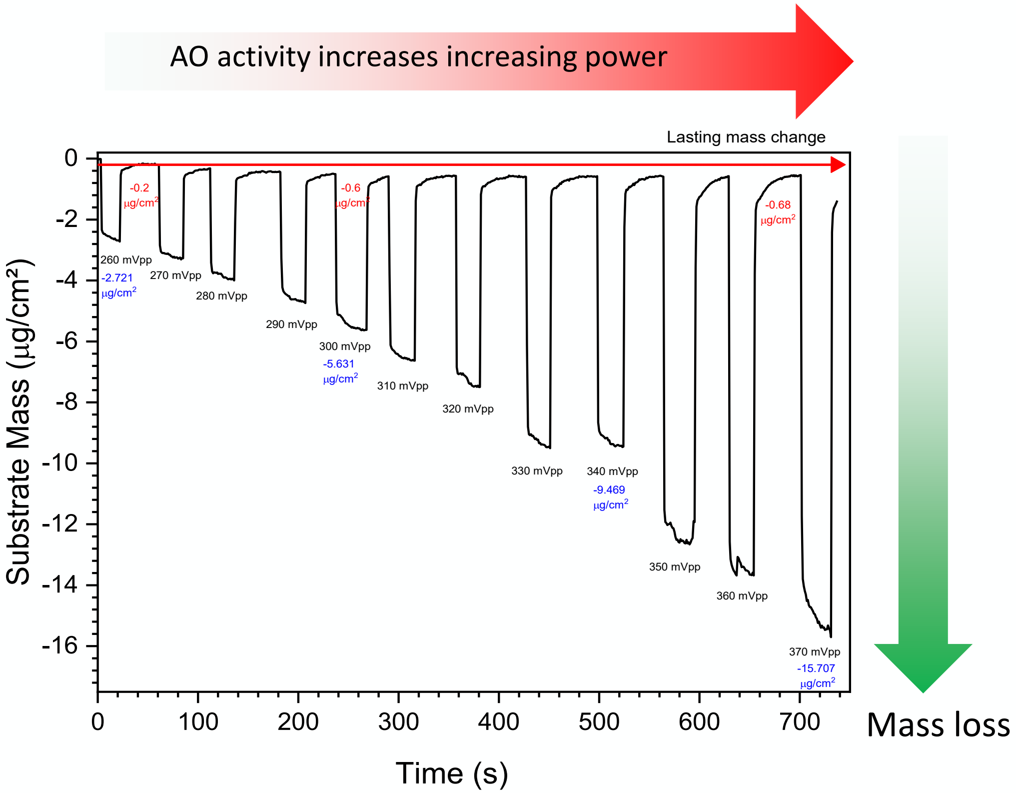
CO, $CO_2 > O_2$ %

3

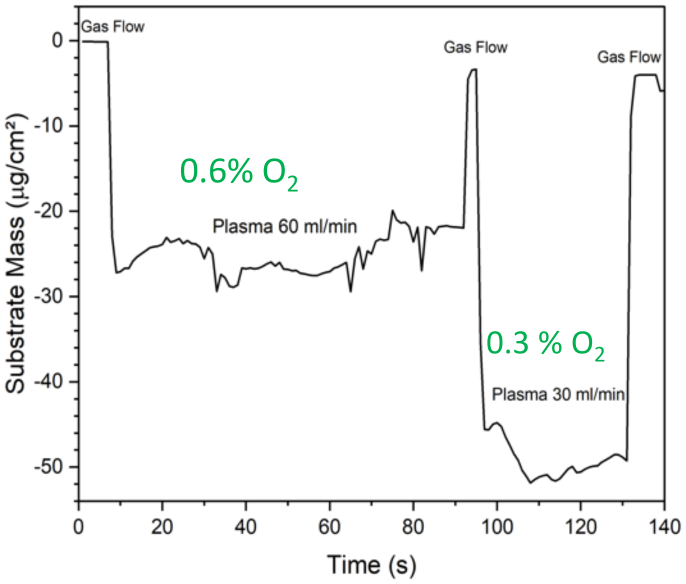


AO activity at different O_2 ratios in He

Tailoring AO for conservation: QCM mass loss measurement as AO probe



Testing QCM AO sensor



AO activity (sample mass loss) at different O_2 ratios to He at 4W

Testing AO on CH materials: substrates and challenges

MOXY esa

Substrates

- **Organic substrates** (cotton, paper, silk, wood)
- **Sensitive paints** (gouache, pastel, acrylic and oil paints)
- **Raw pigments**
- **Porous inorganic substrates** (plaster, alabaster, ceramics, glass)
- **Problematic plastics** (PMMA, PVC)
- **Biomaterials** (feathers, leather, bone)
- **Metals** (high polish alluminum, copper, steel, silver)

Challenges

- **Non-contact cleaning without health and environental concerns**
- **Tailored for delicate mechanically unstable materials**
- **Cleaning materials sensitive to water and organic solvents**
- **Limit tansport of contaminants / residues into porous substrates**
- **New ways to remove toxic biocides and biological contaminants**
- **Non-contact cleaning sensitive high – polish surfaces**
- **Explore synergies with existing cleaning methods**
- **Radically new cleaning methods based on reactive species**

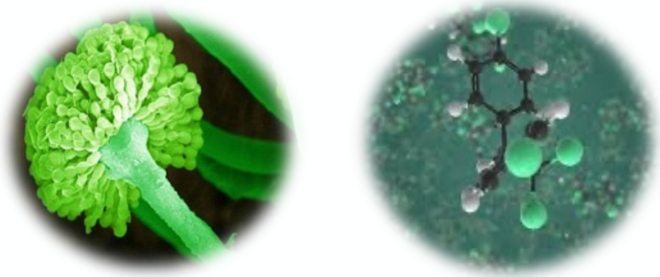
Testing AO on CH materials: the contaminants

Deposited contaminants

Soot | Surface dirt | Wax on metals

Degradation products

Cotton yellowing? | Fatty acid exudates



Microorganisms ? | Biocides ?

Lead white darkening? | Sulfides on silver?

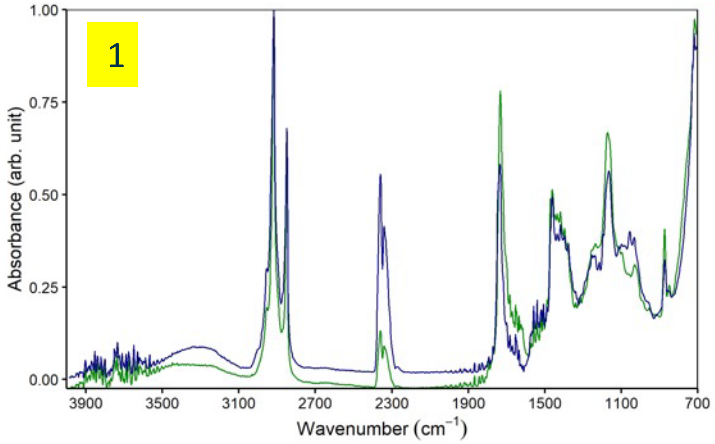
Handling & defacement

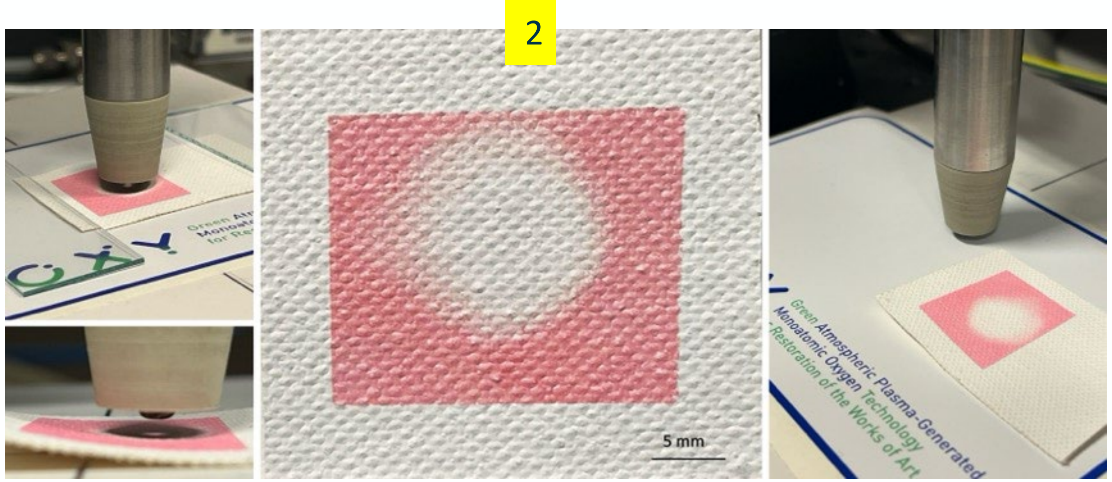
Fingerprints | Lipstick | Markers, ball-point pen | Graphite pencil | Coffee

Testing AO on CH materials: Andy Warhol lipstick mockup

Eva Szabo (Warhol) lipstick (green) and Boho Desiree 312 lipstick (blue)

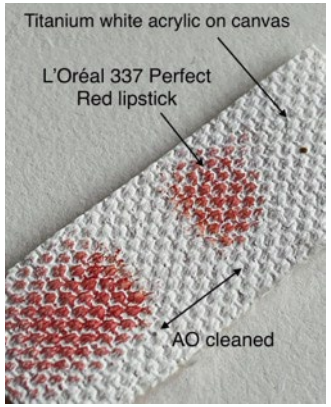
Boho lipstick *Desire 312* composition:
Castor Oil, Hydrogenated Olive Oil, Stearyl Esters, Oleic-Linoleic-Linolenic Polyglycerides, Carnauba Wax, Candelilla Wax, Carmine Ci 75470, Titanium Dioxide Ci 77891, Iron Oxides Ci 77491, Fragrance, Tocopherol.

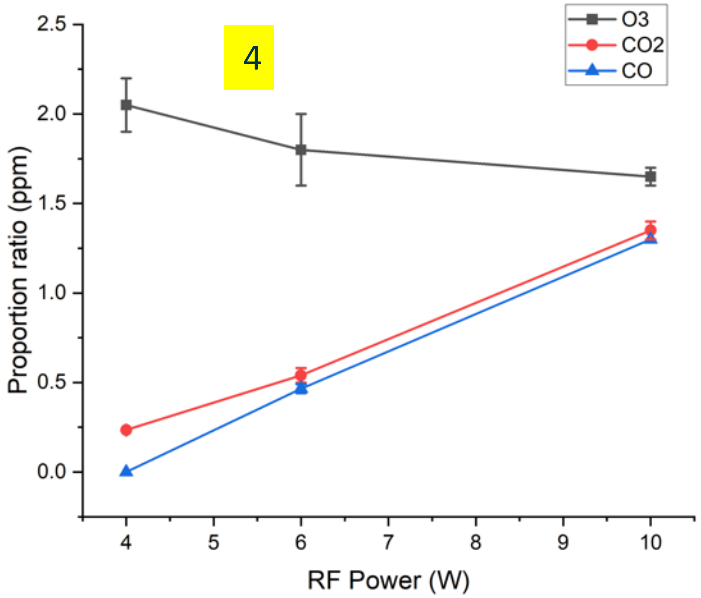


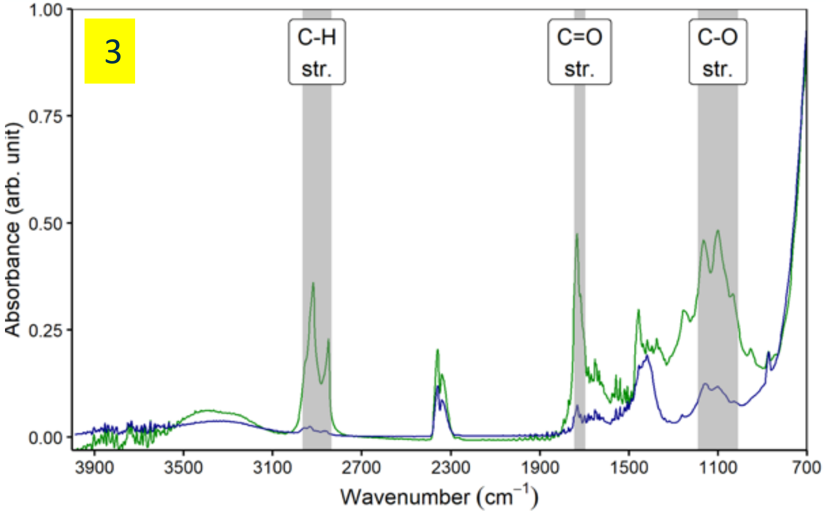


AO cleaning process: 4,56 W 90 min, T 39 C

Volatile species CO and CO_2 from AO reaction with the lipstick

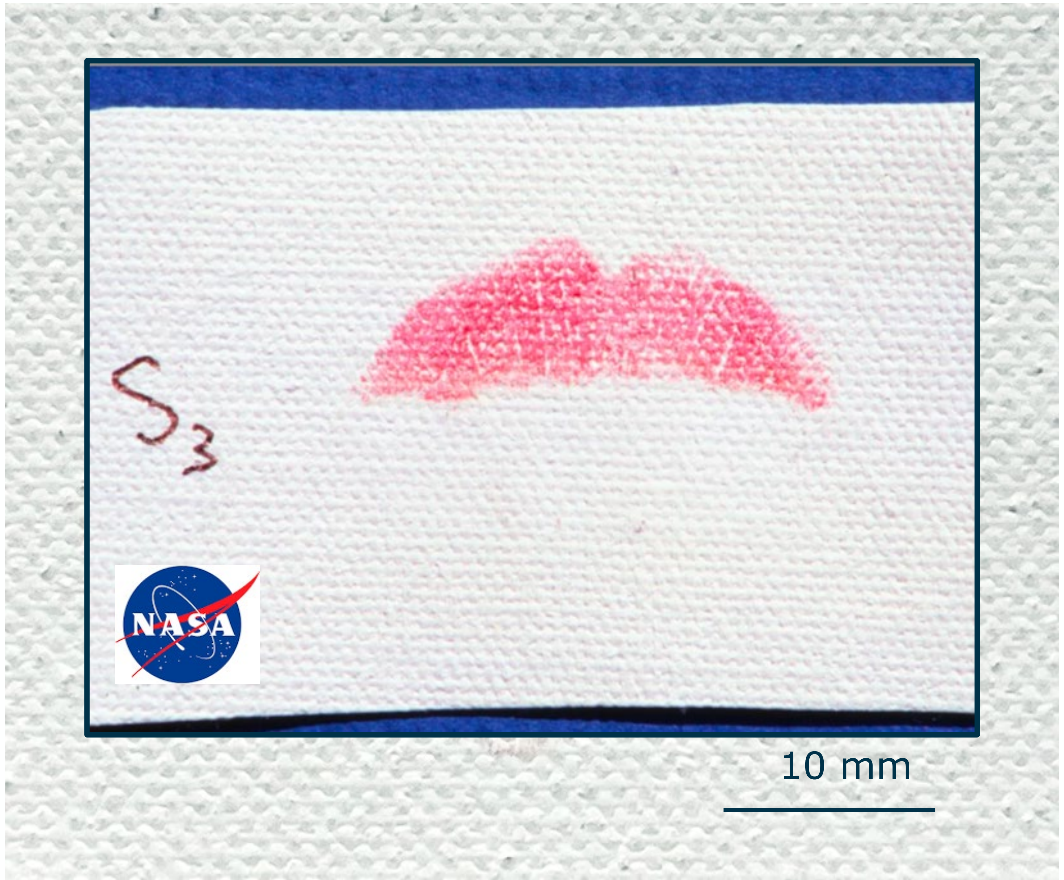






FTIR-ATR spectra measured in Boho lipstick (green) and AO-treated (blue) show chemical changes to lipstick composition. Reduction of peak intensity in C-H, C=O, and C-O stretching bands related to esters and aliphatic compounds indicates the removal of the organic binding medium. C-H bonds may be related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

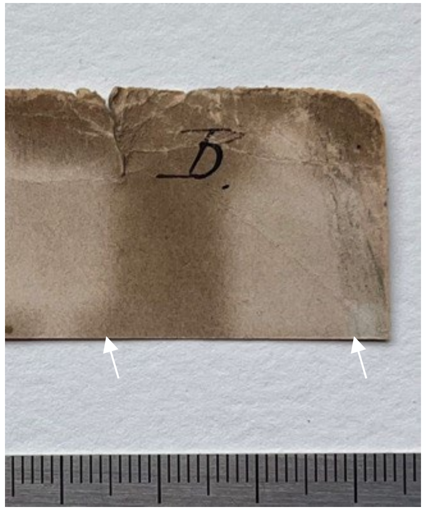
Testing AO on CH materials: lipstick on acrylic paint

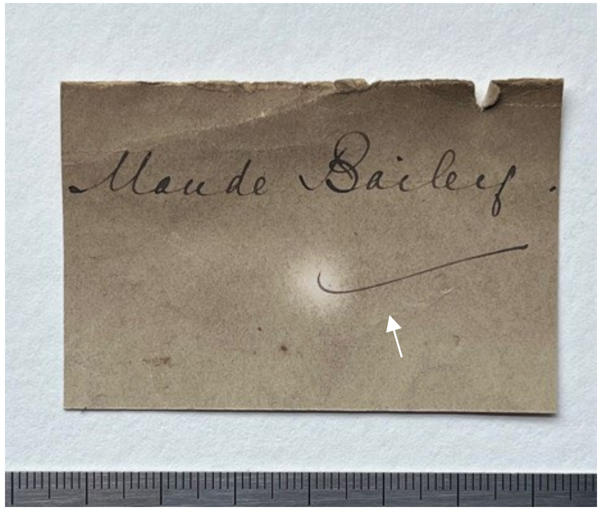


L'Oreal 337 Perfect Red lipstick on cotton duck canvas primed with acrylic paint. Half lipstick removed with AO (right)

Testing AO on CH materials: natural and artificial soiling

Natural soiling

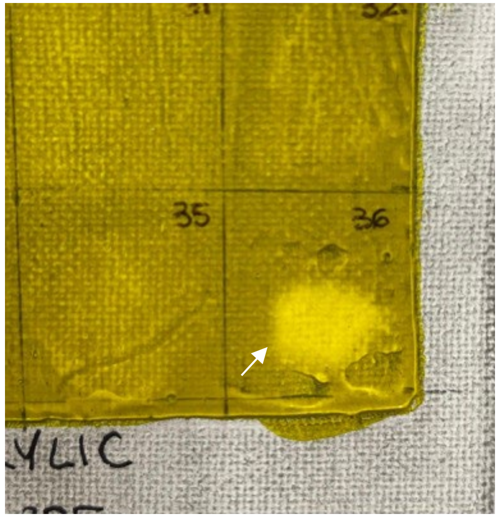




Paper (1896) with ink signature and natural surface dirt with AO cleaning tests

AO tested positive on both natural and artificial soiling; however, depending on chemical composition, not all natural and artificial soil can be treated using AO

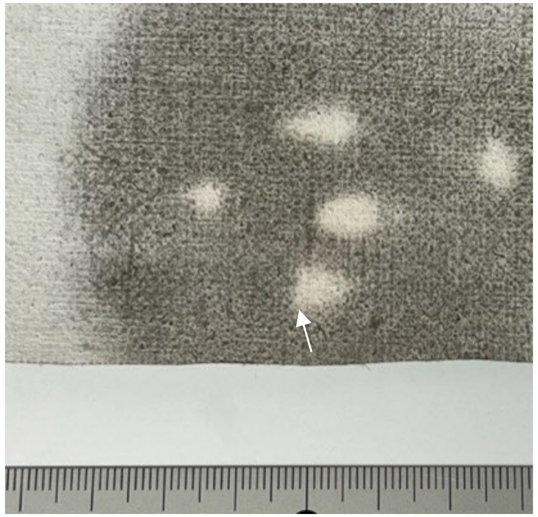
Model soiling



"Tate mixture" with AO cleaning

Composition % by mass:

Carbon black 0.2
Iron oxide 0.1
Kaolin 2.4
Gelatin powder 1.2
Starch 1.2
Cement (Type1) 2.1
Olive oil 1.2
Mineral oil 1.9
VM&P naphtha 89.6

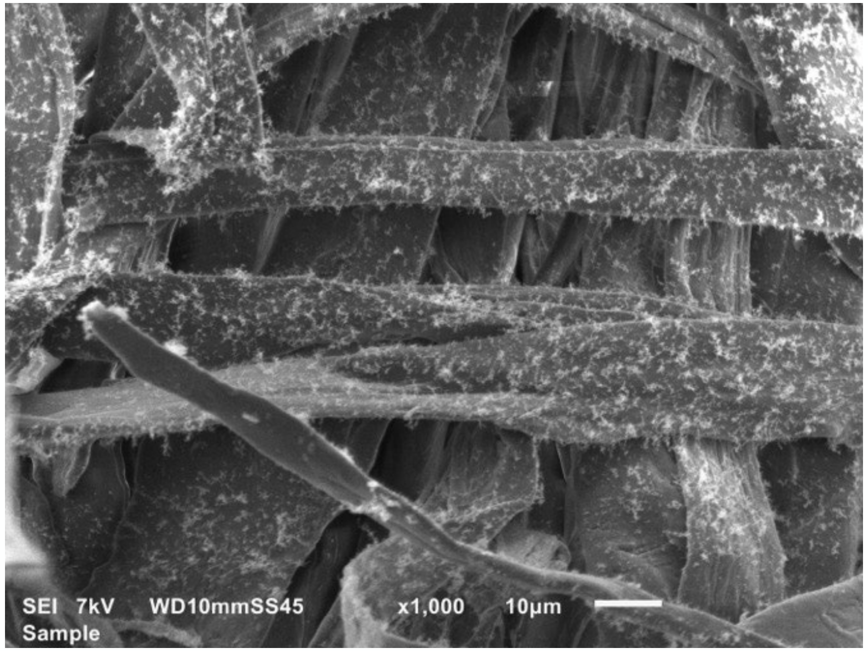


C5 ISO 11378-2 standard soiling with AO cleaning spot tests.

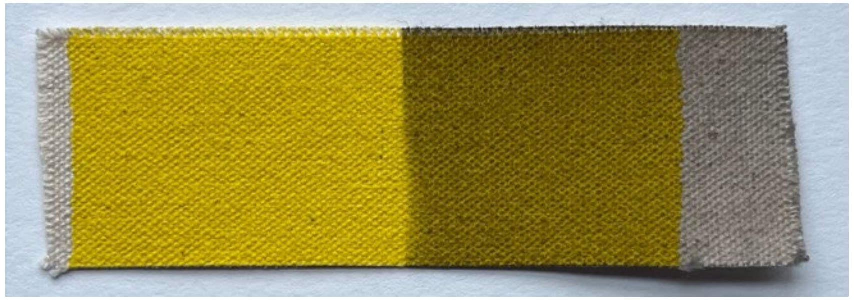
Composition % by mass:

Peat moss 38
Portland cement 17
Silica (200 mesh) 17
Carbon (lamp black) 1.75
Red iron oxide 0.5
Mineral oil 8,75

Testing AO on CH materials: fire-born soot models



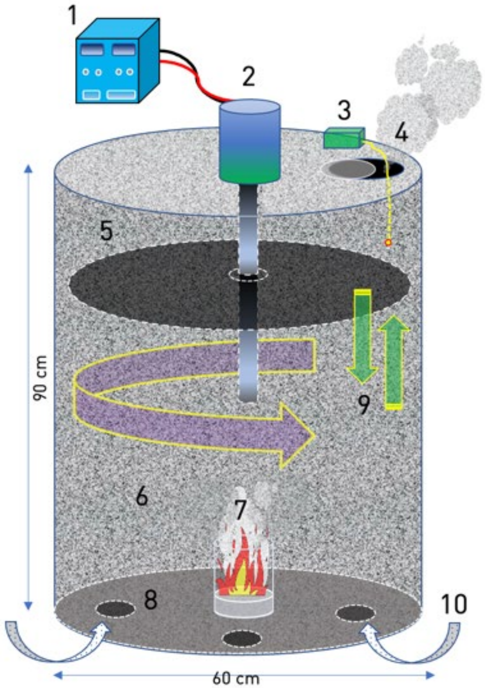
SEM: cotton duck canvas with soot contamination

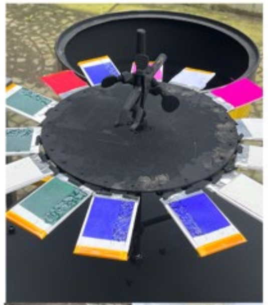


Cadmium yellow acrylic paint on cotton duck canvas with after soot contamination

Soot produced by Shellsol D40 combustion

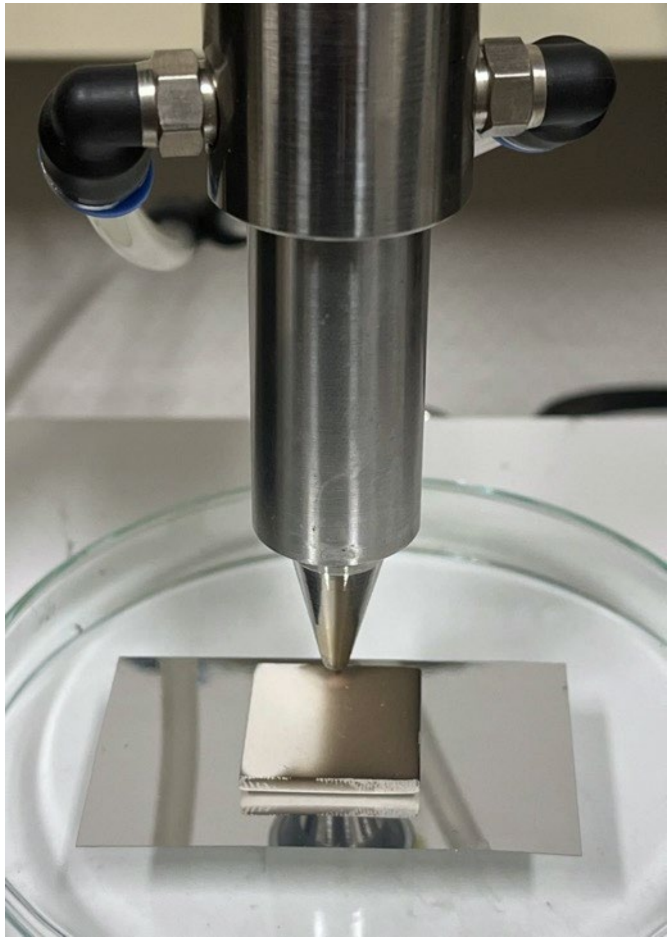
Soot soiling	Shellsol D40 ml.	Time min.	T °C avg.
Light	20	10	43
Medium	50	30	43
Heavy	100	60	43



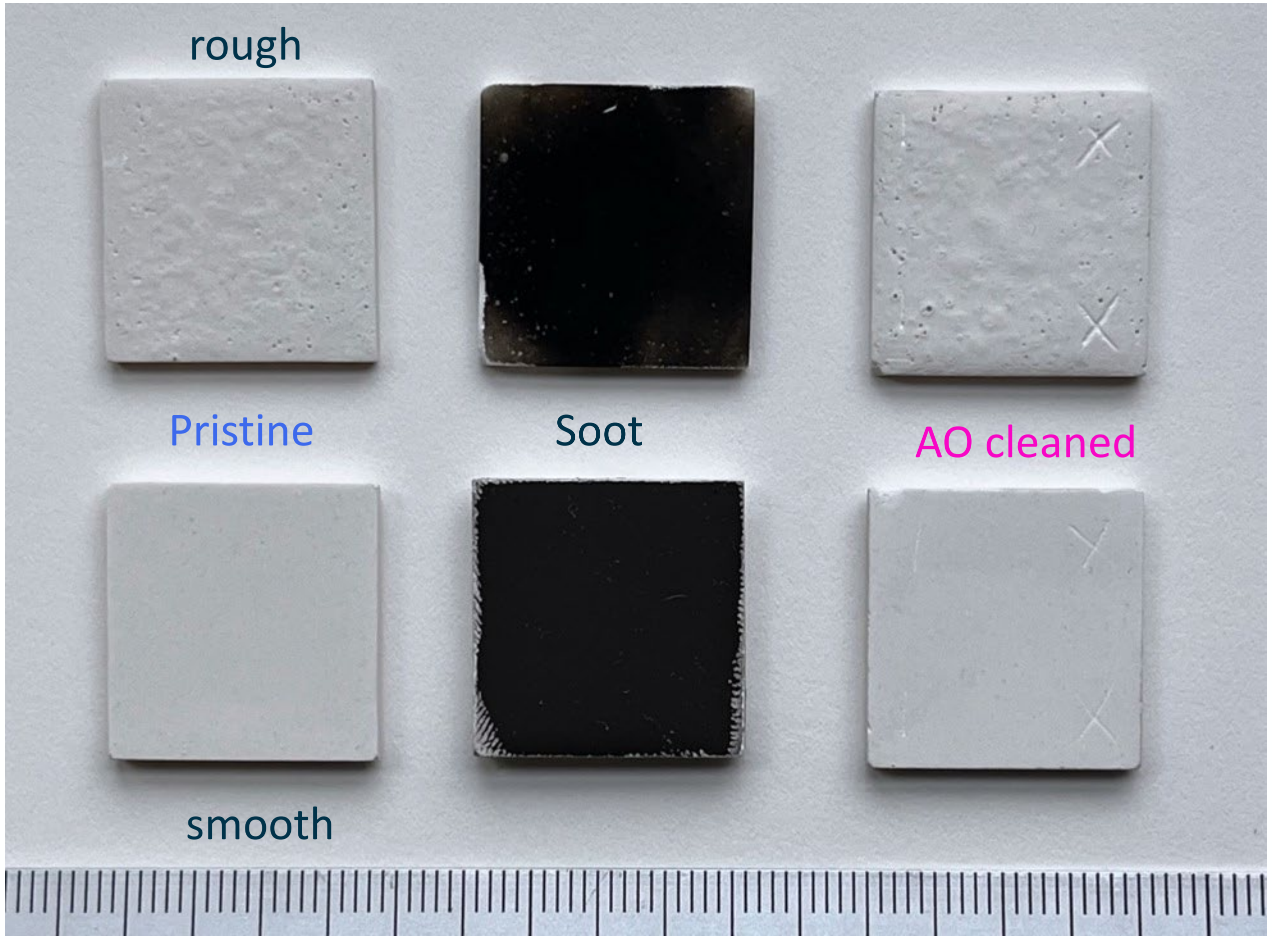


1. Laboratory power supply
2. Electric rotor
3. Temperature sensor
4. Smoke exit
5. Disck with samples
6. Metal chamber
7. Beaker with Shellsol D40
8. Opening for air intake
9. Sample disk can be lifted
10. Air

Testing AO on CH materials: plaster gypsum and porous substrates



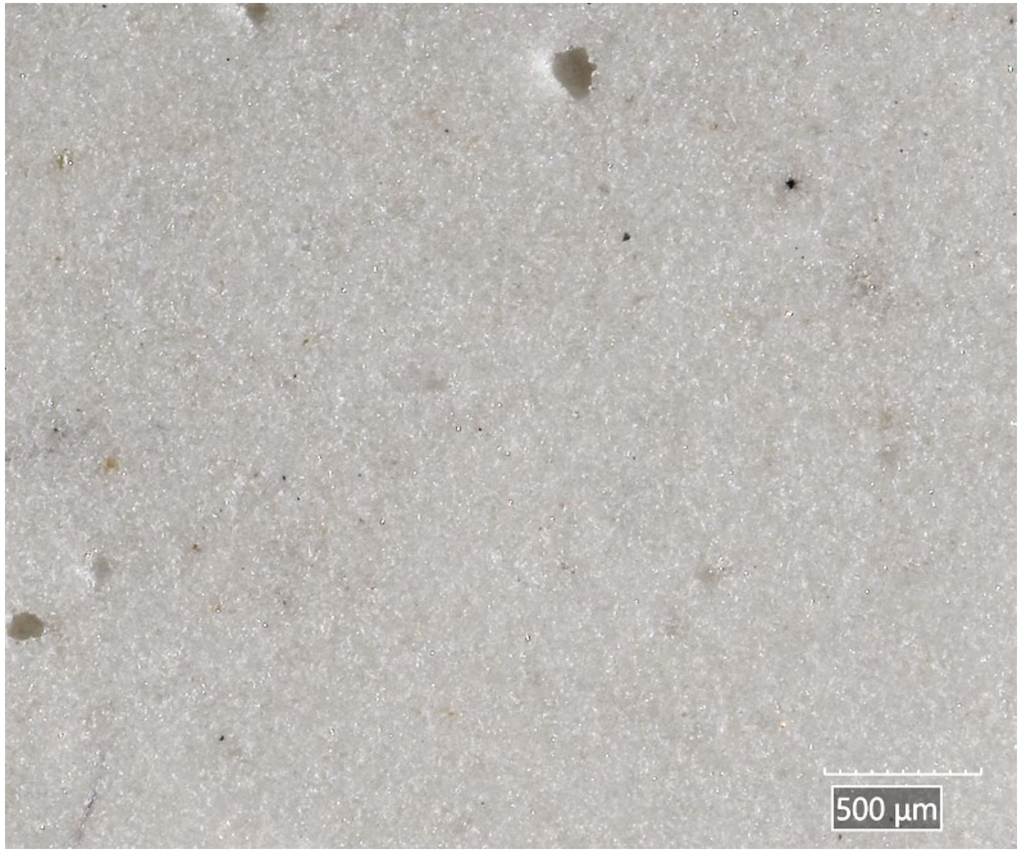
AO cleaning in process



Plaster gypsum mock-ups

Testing AO on CH materials: Soot on plaster gypsum

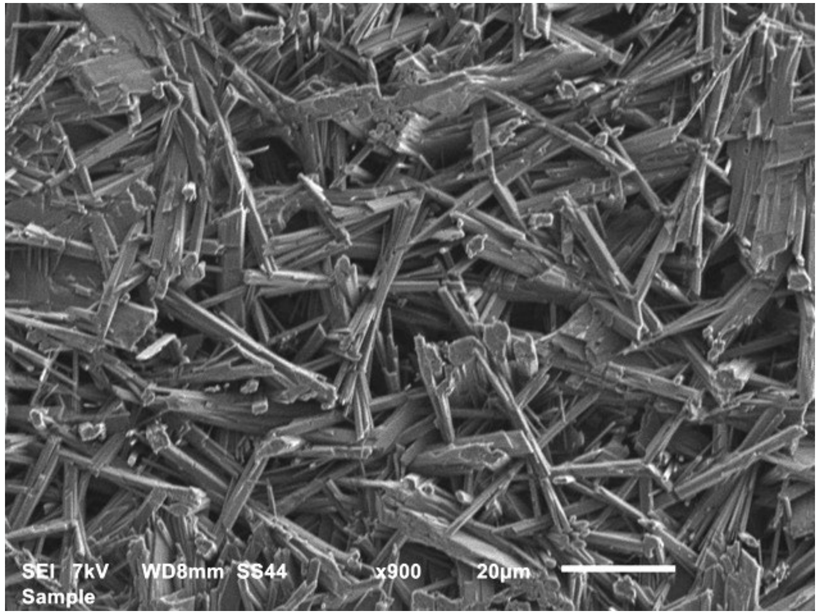
Hirox x 120



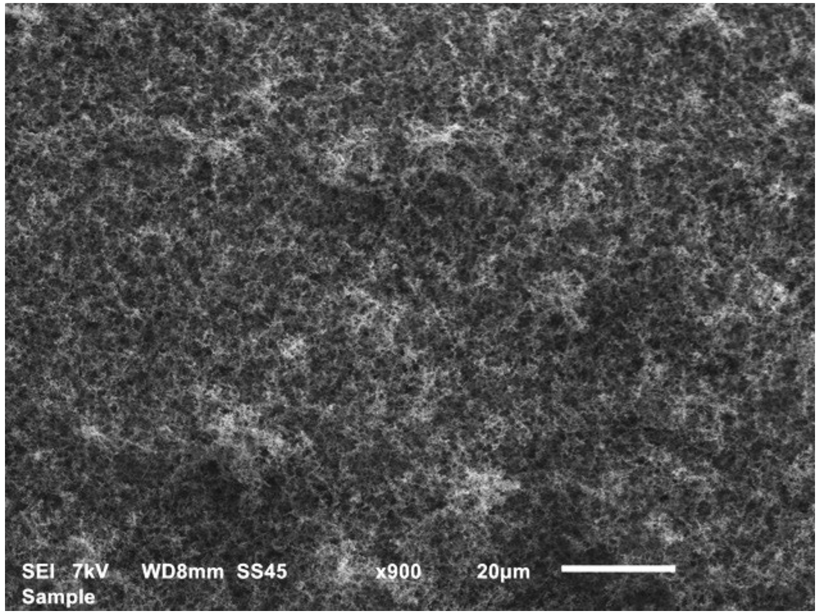
Pristine

AO cleaned

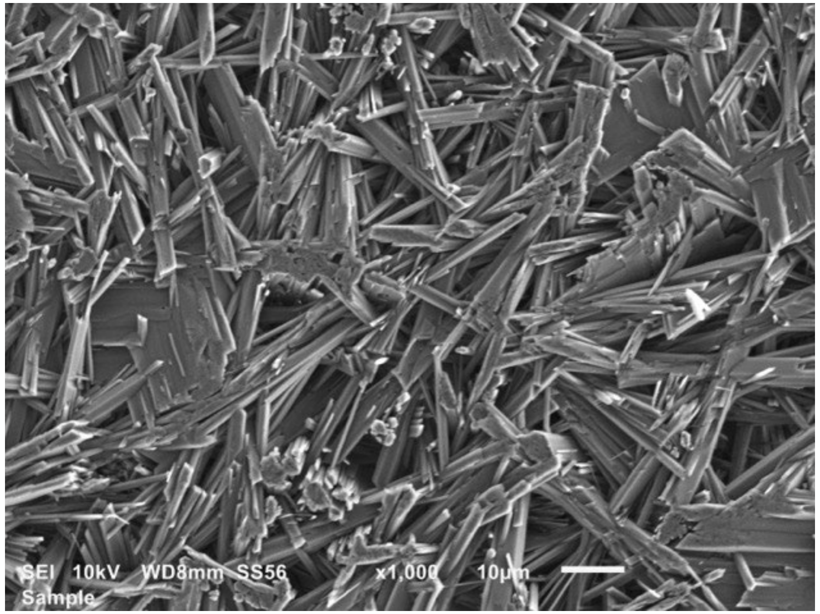
Testing AO on CH materials: Soot on plaster gypsum



Pristine



Soot

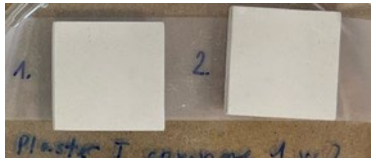


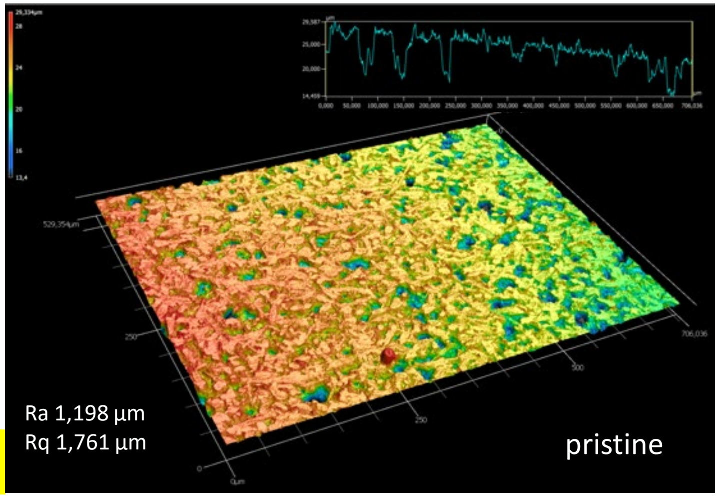
AO cleaned

SEM: plaster microstructure at 900x magnification

Testing AO on CH materials: soot on plaster, impact on microroughness

Plaster, smooth side. Pristine (1) vs. contaminated with soot, and AO cleaned (2)

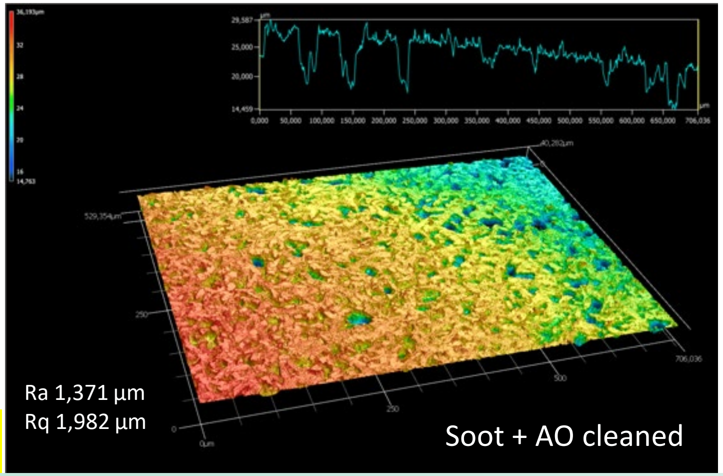




1

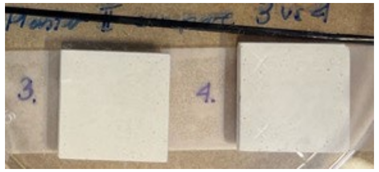
Δ_{Ra} 0.1 µm
Δ_{Rq} 0.2 µm.

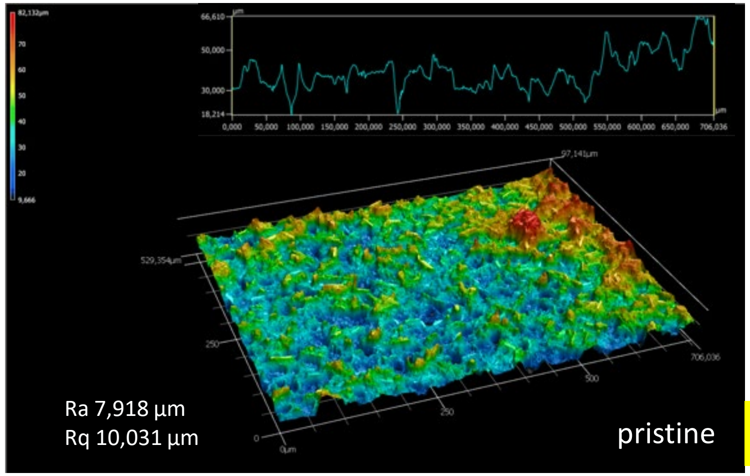
Microroughness increased



2

Plaster, rough side. Pristine (3) vs. contaminated with soot, and AO cleaned (4)

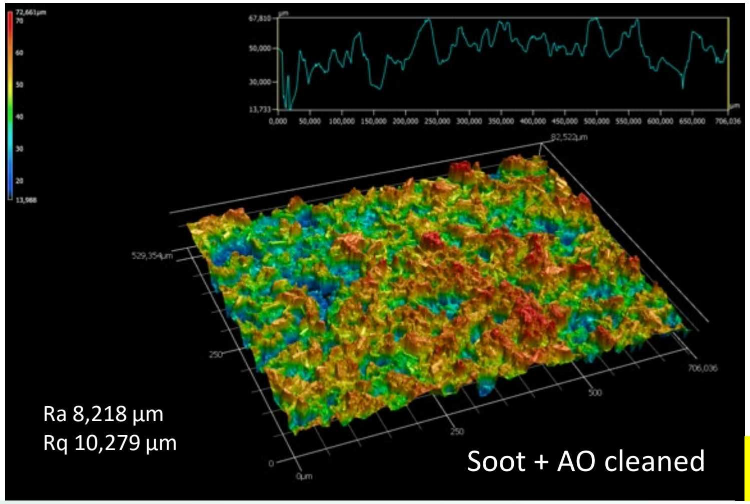




3

Δ_{Ra} 0.3 µm
Δ_{Rq} 0.2 µm

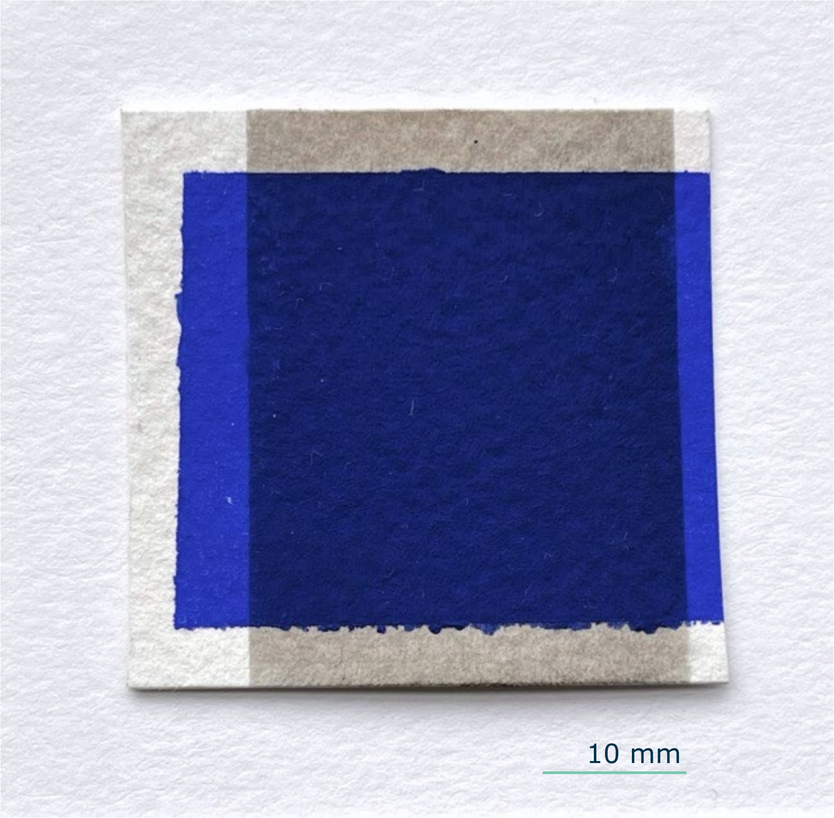
Microroughness increased

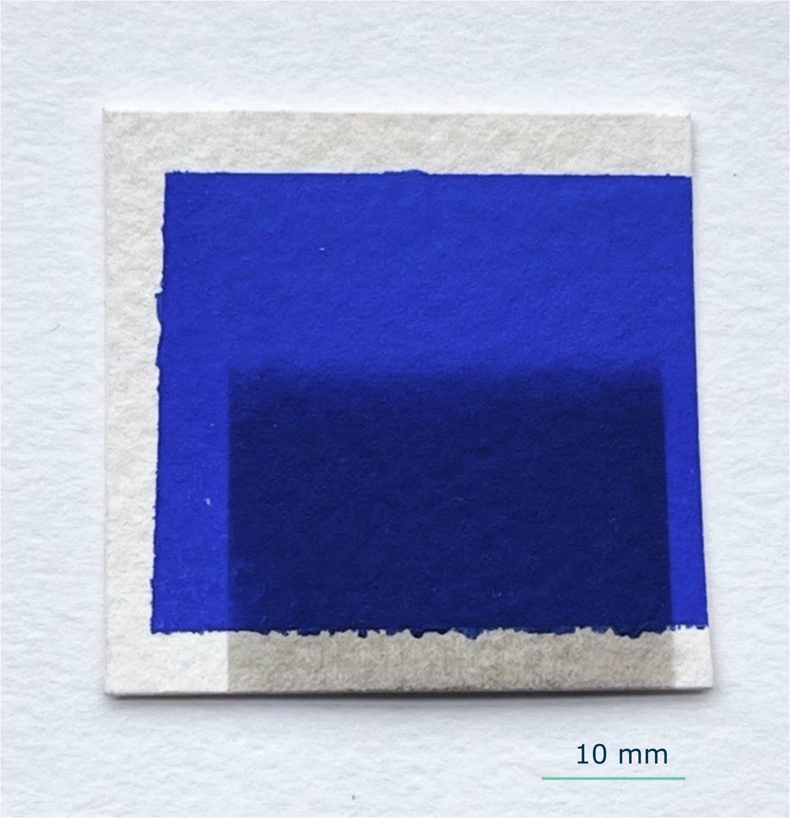


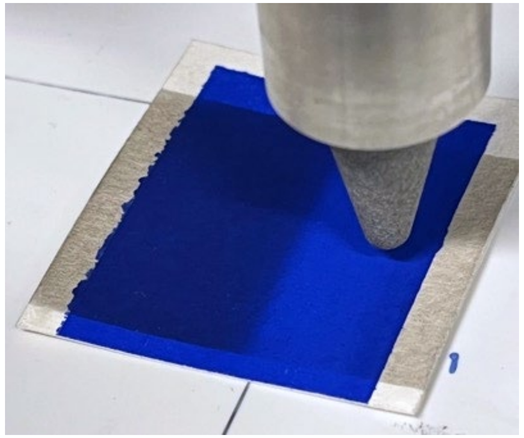
4

Confocal laser microprofilometry CLM: laser scanning microscope Keyence VK-X3000 Concept

AO effects cleaning soot: gouache on paper



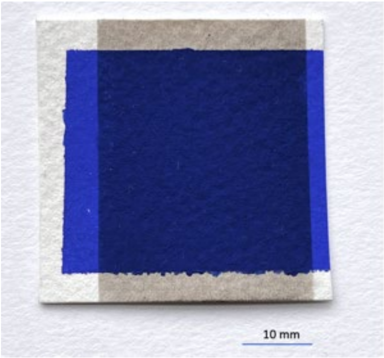


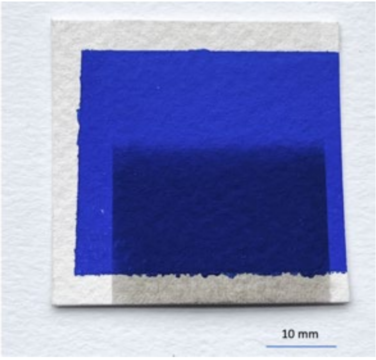


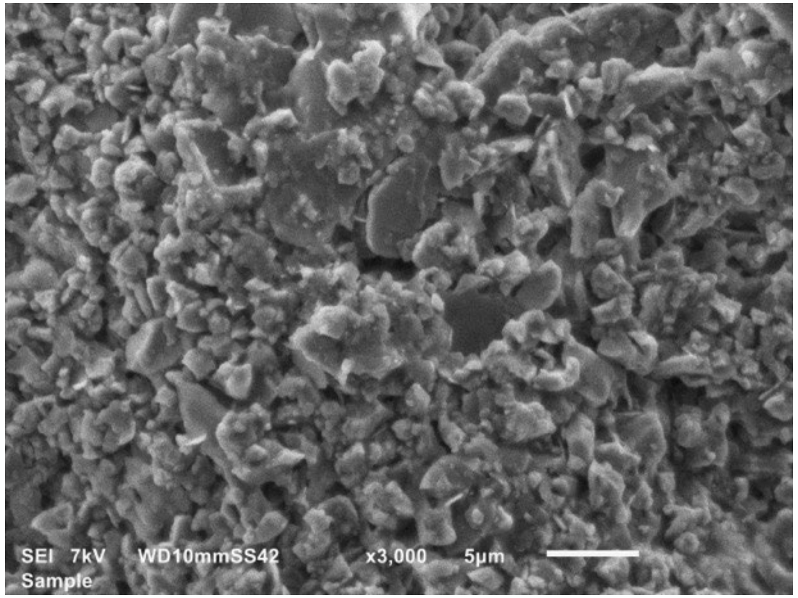
During treatment

Soot on W&A Cobalt Blue gouache / Arches Aquarelle cold-pressed paper

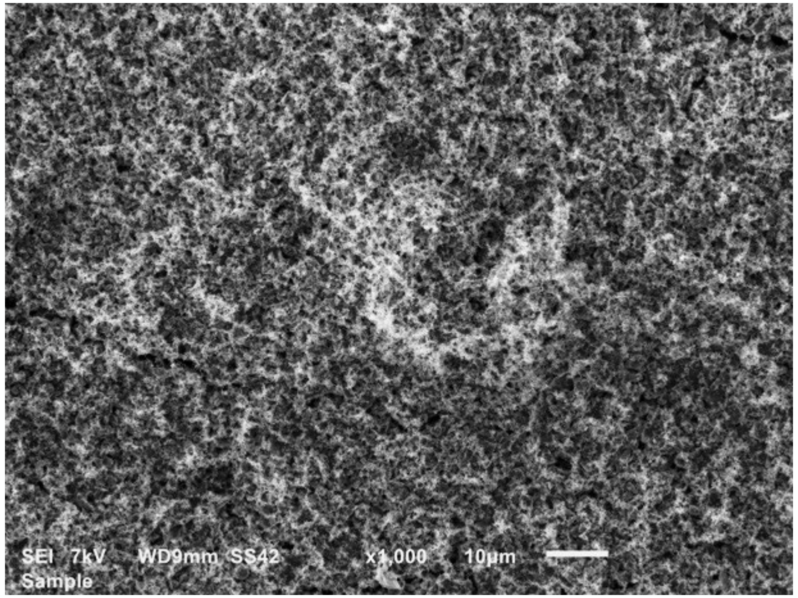
AO effects cleaning soot: gouache on paper



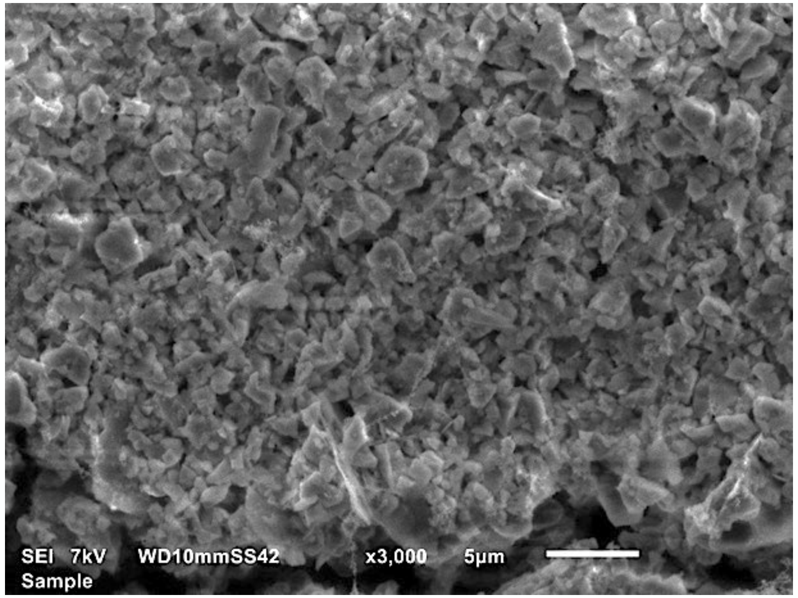




Pristine paint



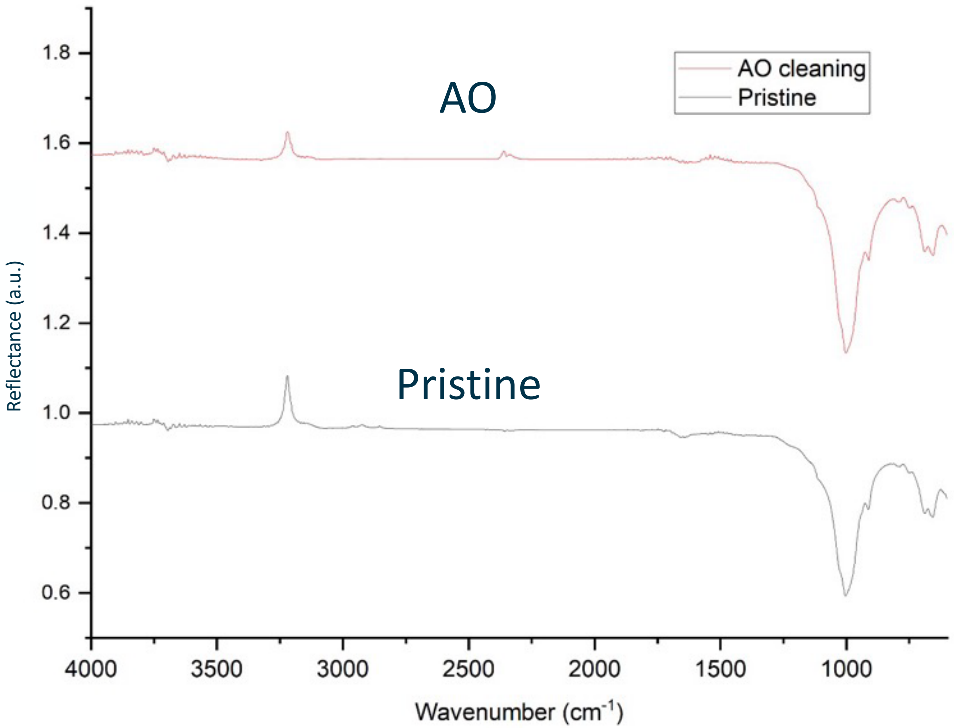
Soot on paint



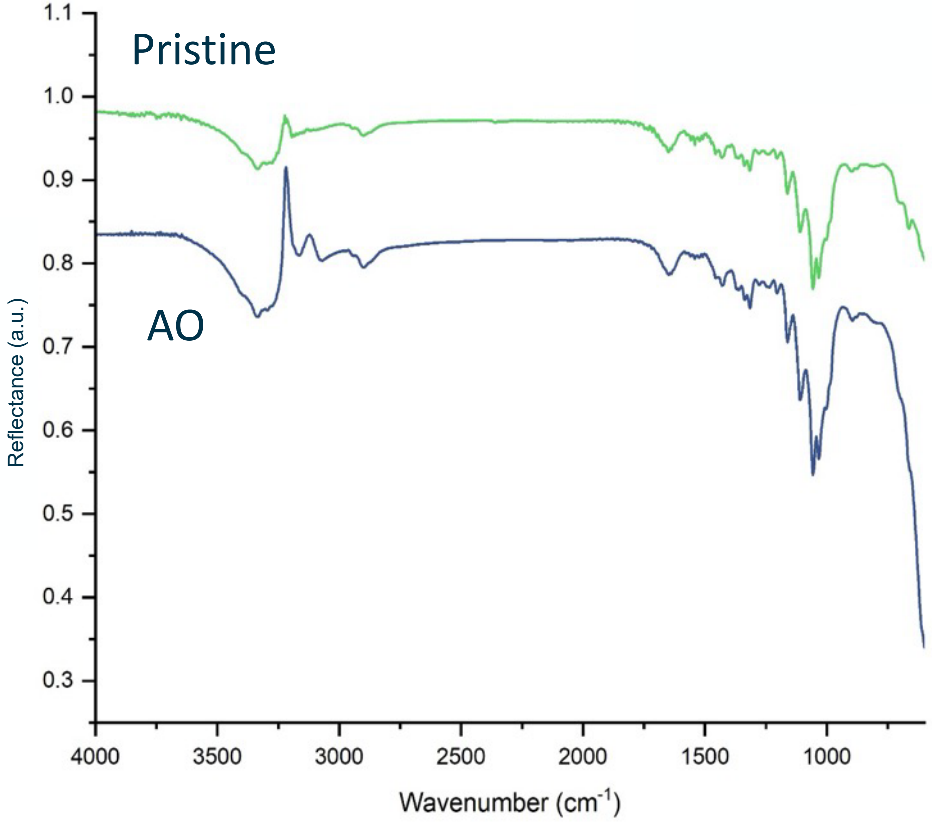
AO cleaning

AO effects cleaning soot: gouache on paper, and chemical changes

µATR-FTIR



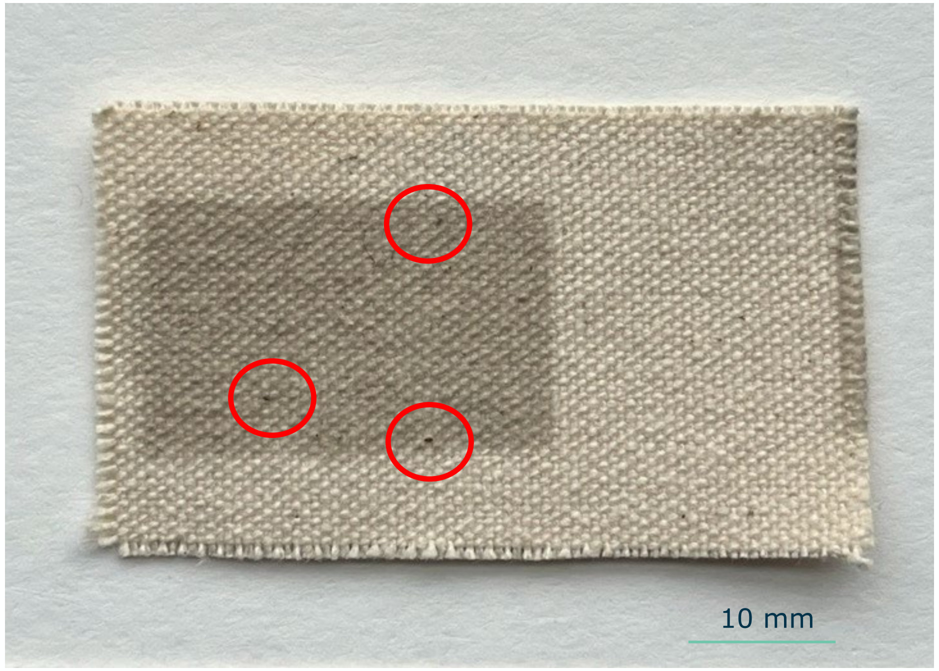
W&N Gouache Paint



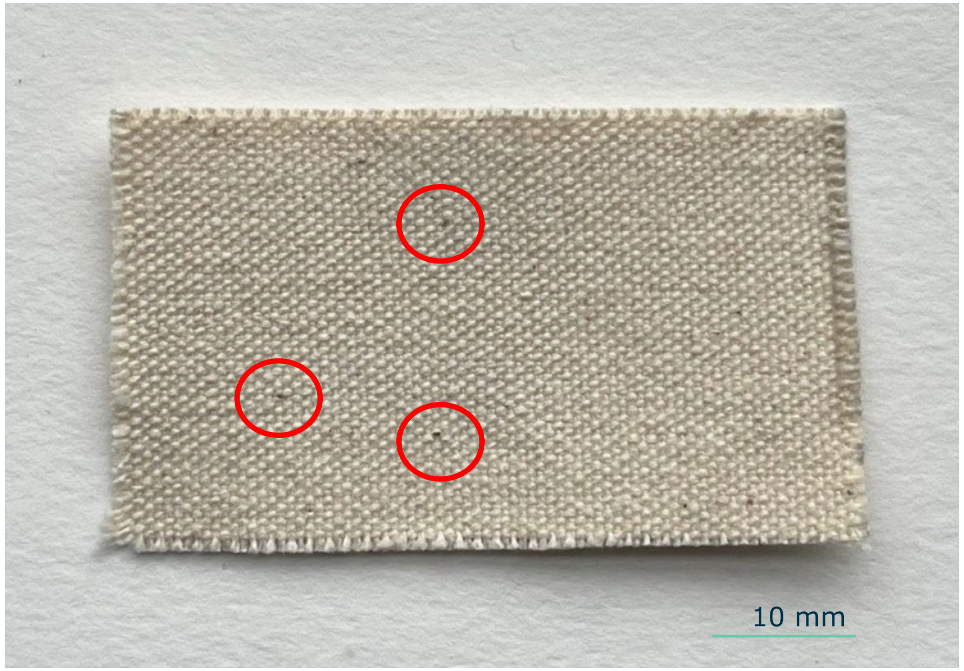
Arches Aquarelle Paper

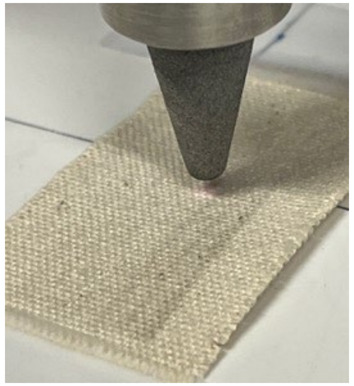
AO effects cleaning soot: unprimed cotton duck canvas

Soot



AO cleaned

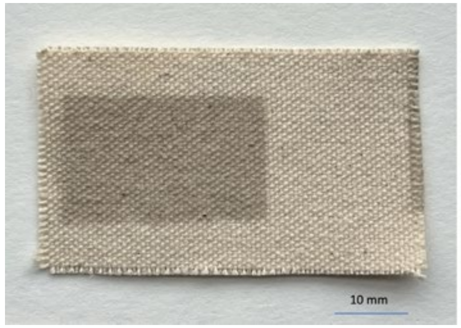




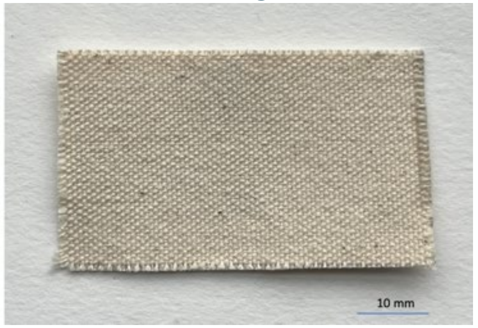
Cotton duck canvas/soot (left). AO cleaned preserved inherent lignin impurities

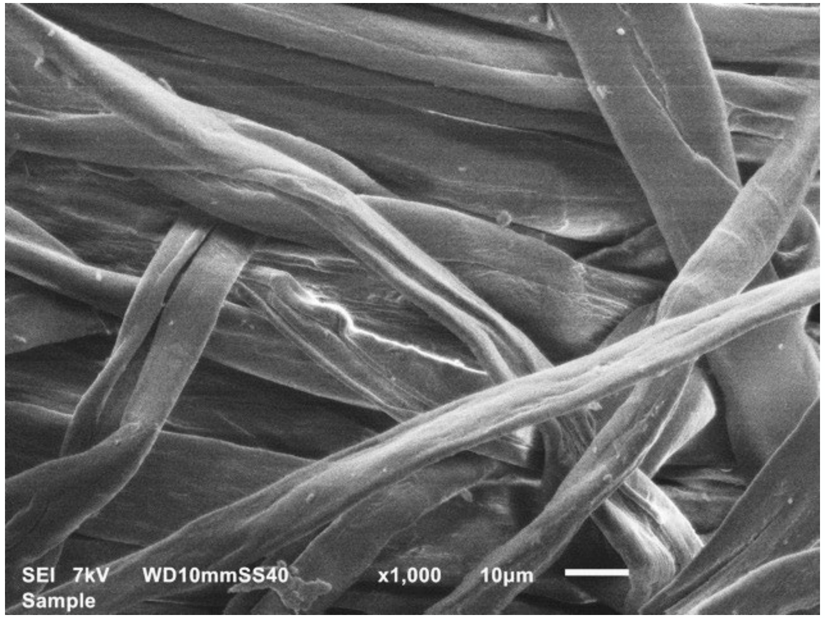
AO effects : unprimed cotton duck canvas

Soot

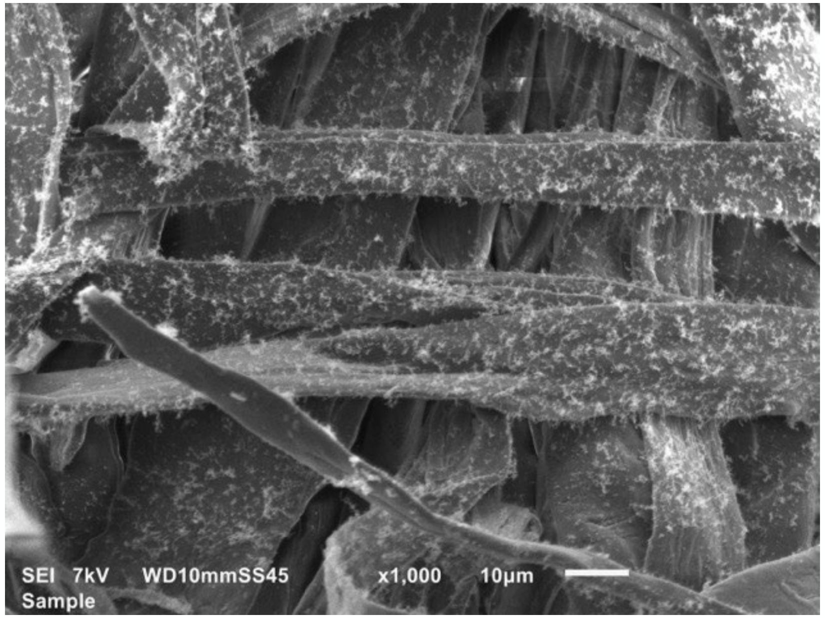


After AO cleaning

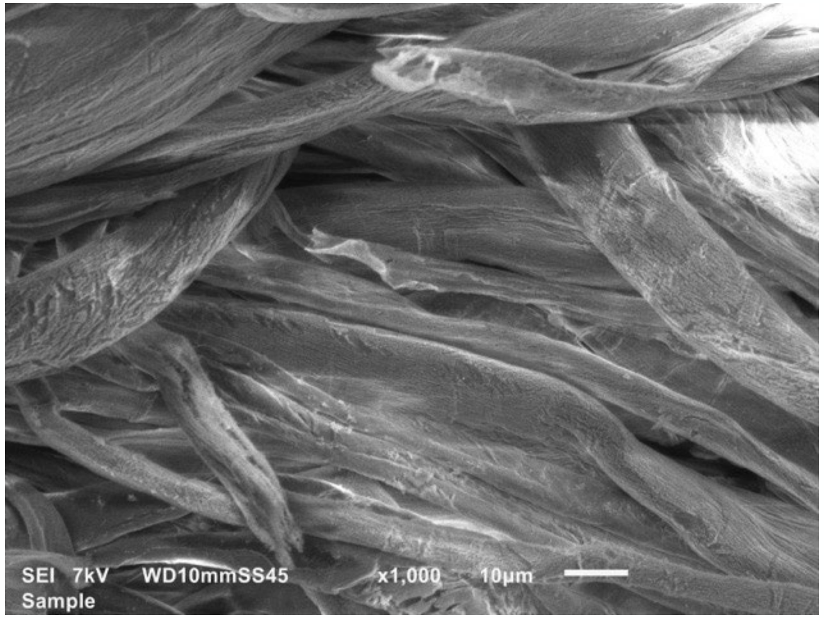




Pristine



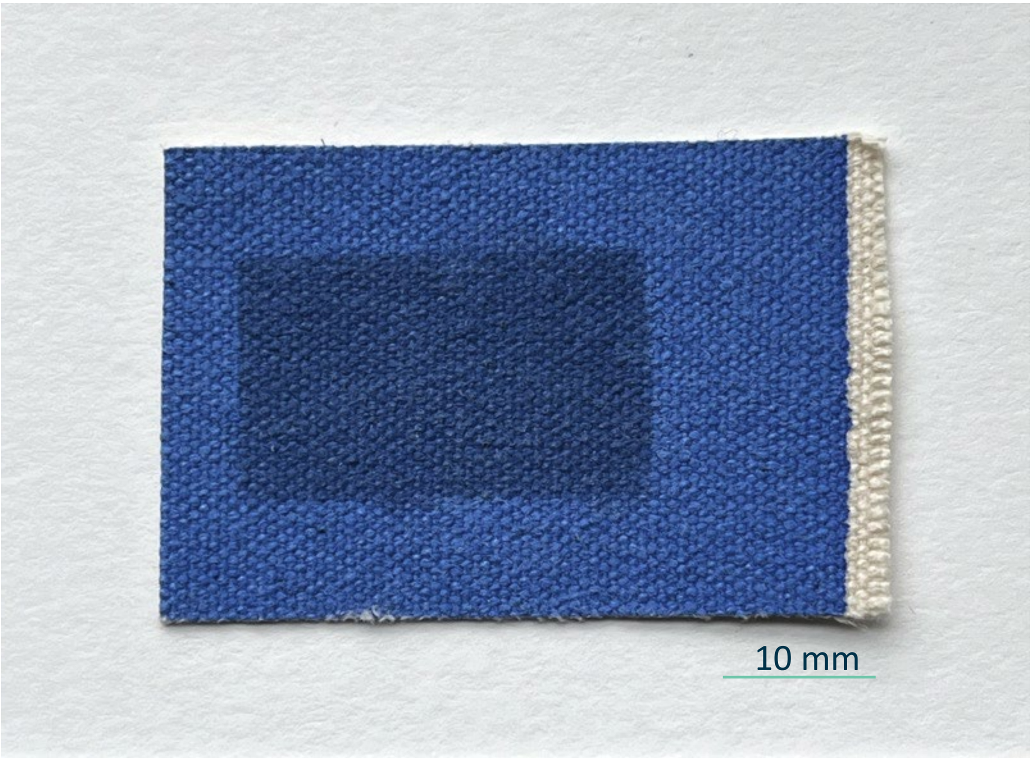
Soot on cotton



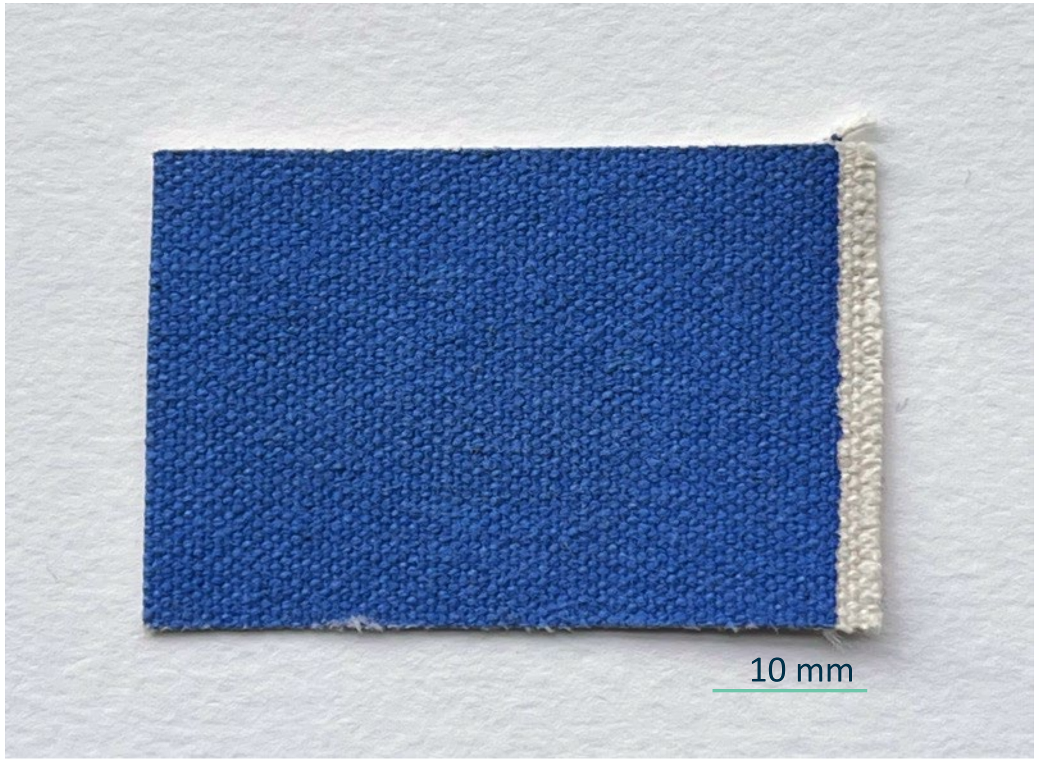
AO cleaning

AO cleaning: soot on acrylic paint, unsized cotton duck canvas

Before



After



Golden Cobal Blue easy-flow acrylic on cotton duck canvas/soot (left). Cleaned using atomic oxygen AO (right)

AO cleaning soot on Golden acrylic paint on unsized cotton duck canvas

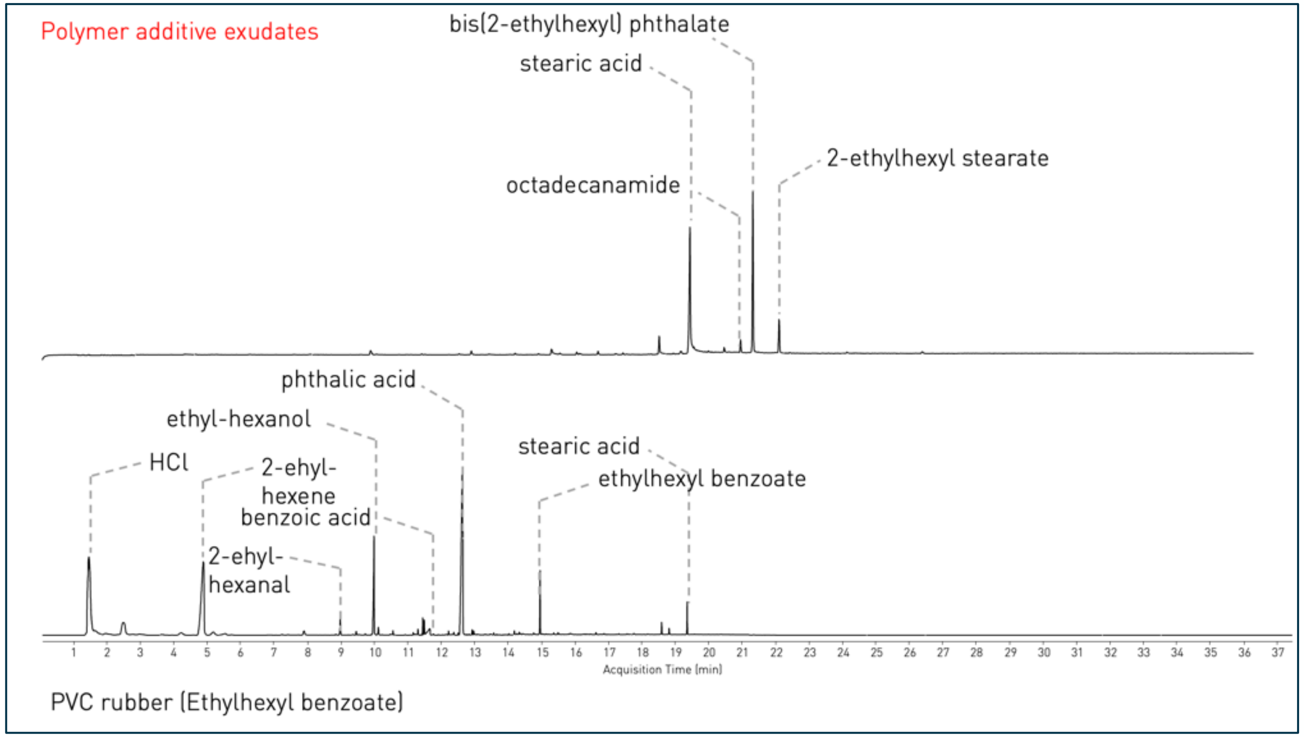
Pristine

After AO

High-definition 3D microscopy (Hirox)

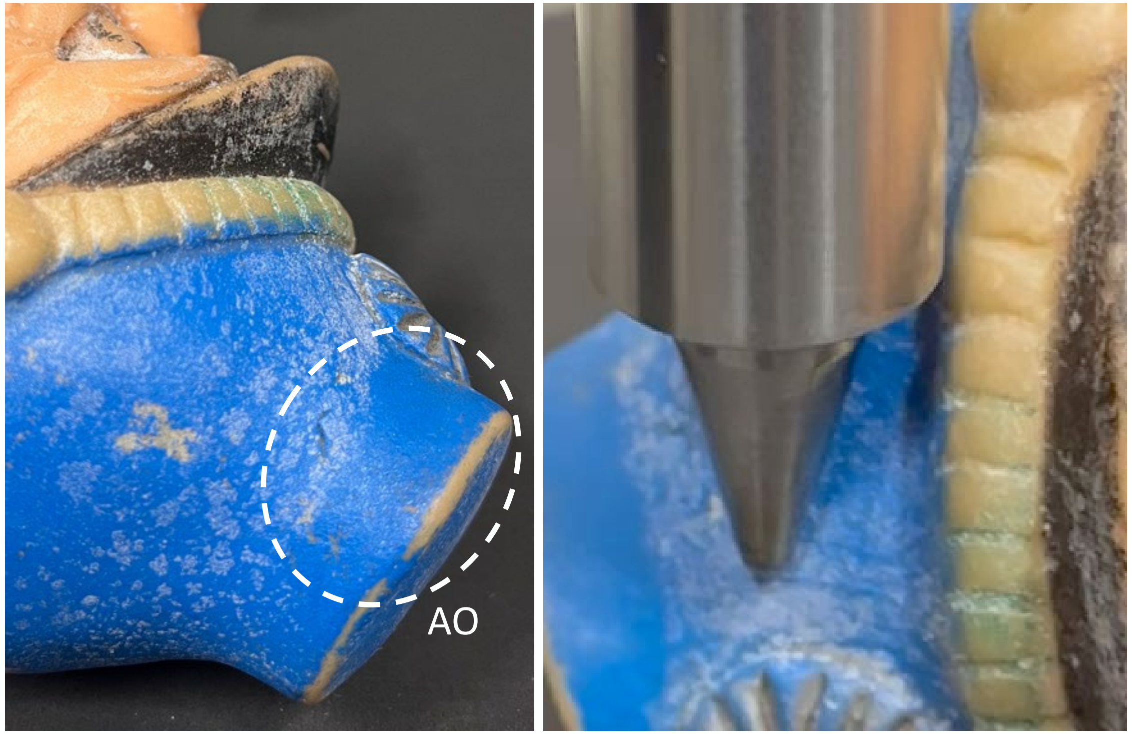
MOXY esa

AO testing on plastics: fatty acid exudates on PVC



Analysis of exudates using Py-GC-MS. The additives were thermally desorbed at 350°C while the polymer pyrolysis was performed at 600°C. A mixture of stearate/stearic acid and phthalates (2-ethylhexyl stearate, 2-ethylhexyl phthalate, other). **Py-GC-MS a**nalysis by Jacopo La Nasa, UNIPI.

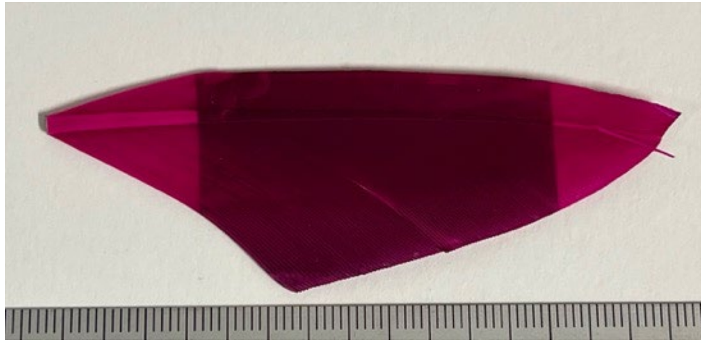
- The AO effect was nearly instant at 36.9 °C, below the melting point of stearic acid at 69.3 °C.
- Heating at ~40 °C did not produce the same effect.



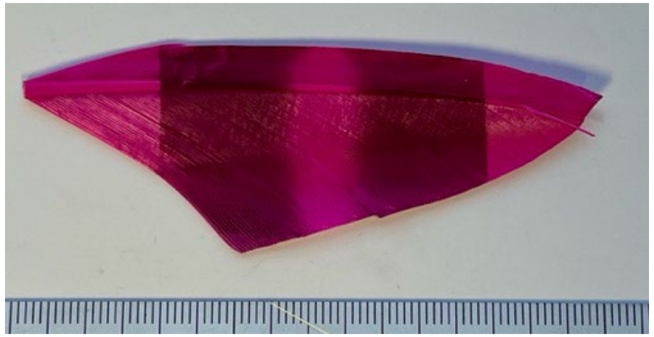
AO treatment of fatty acid exudates on PVC: T.Markevicius (UGent), J. Bobeck, M. Florescu (Modernamuseet).

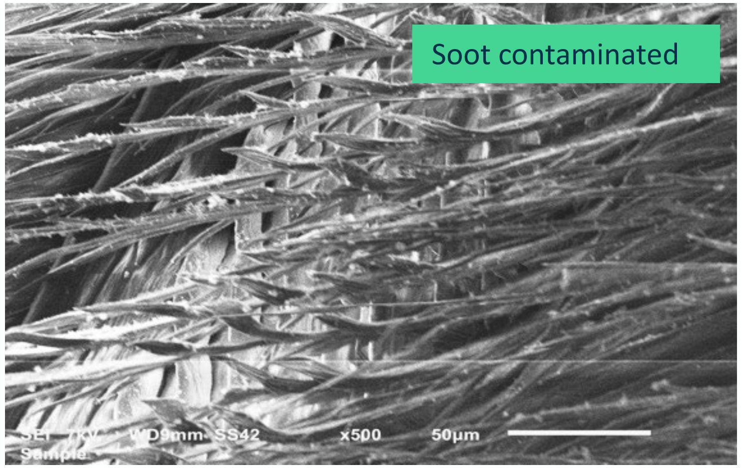
AO effects cleaning soot: feathers

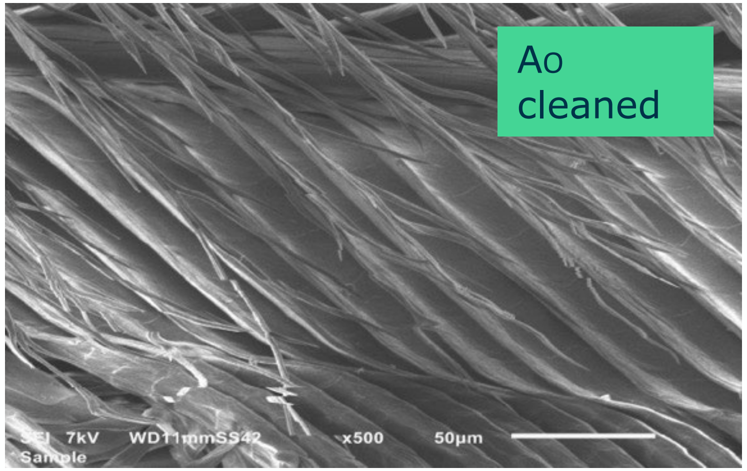
Soot



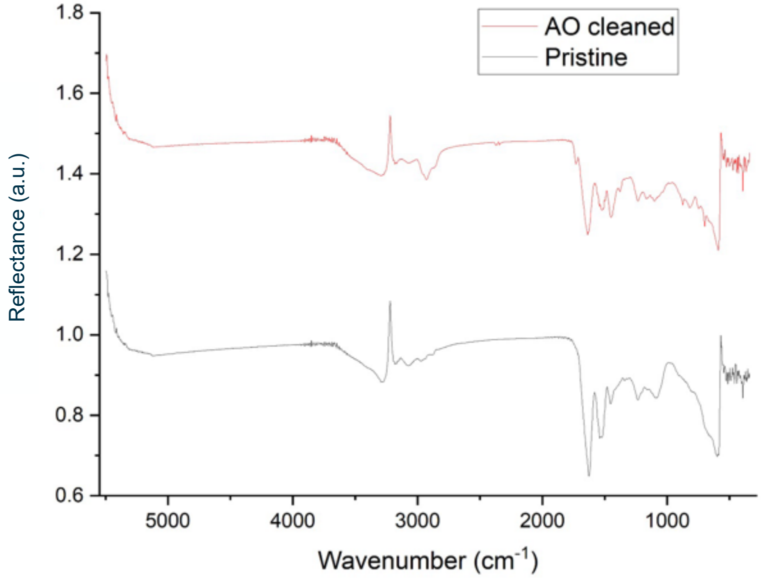
AO cleaned





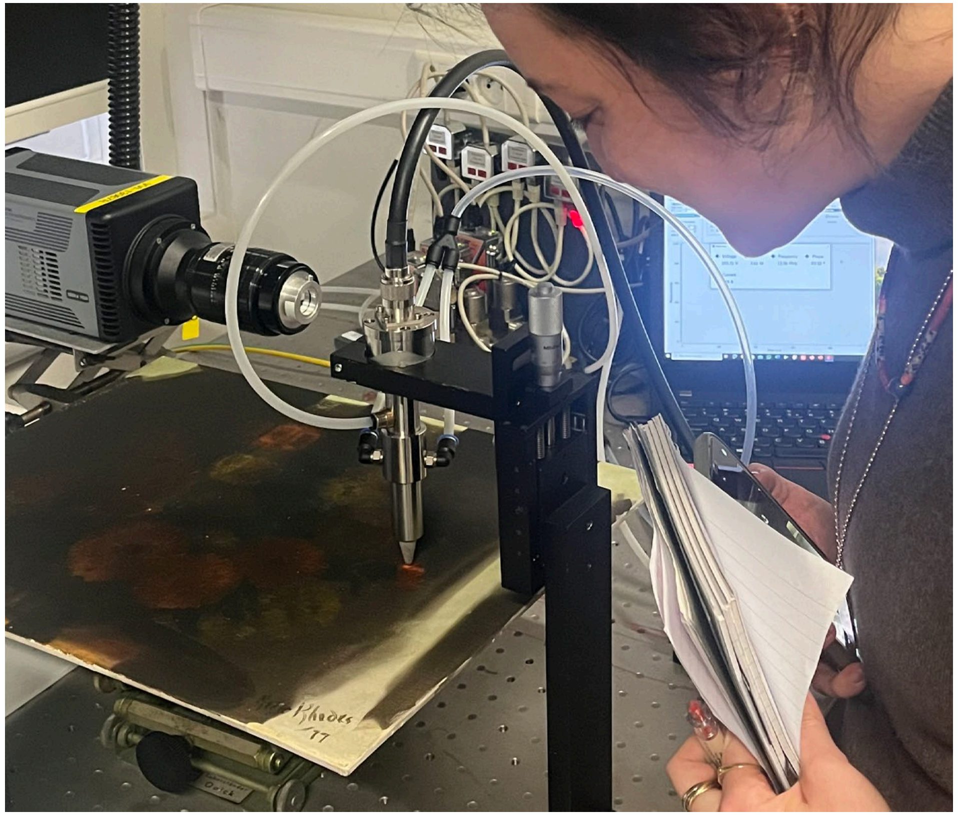


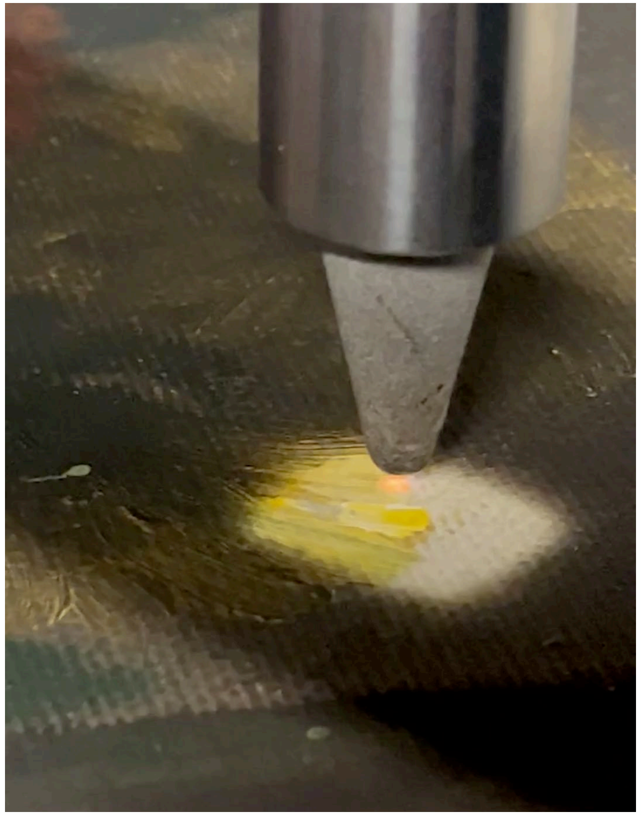
SEM: Natural feathers contaminated with fire-born soot and AO cleaned

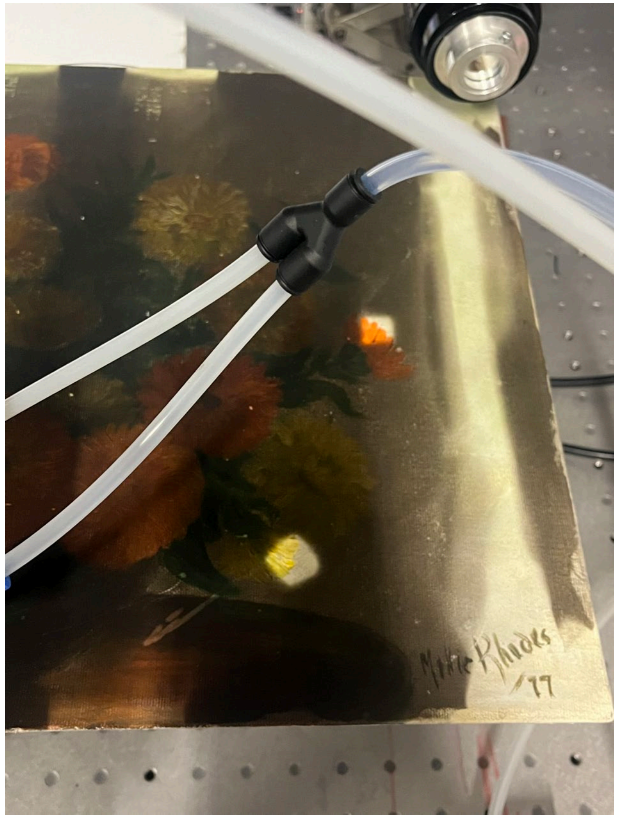


FTIR-ATR

From lab to works of art: AO cleaning soot on 1977 oil painting





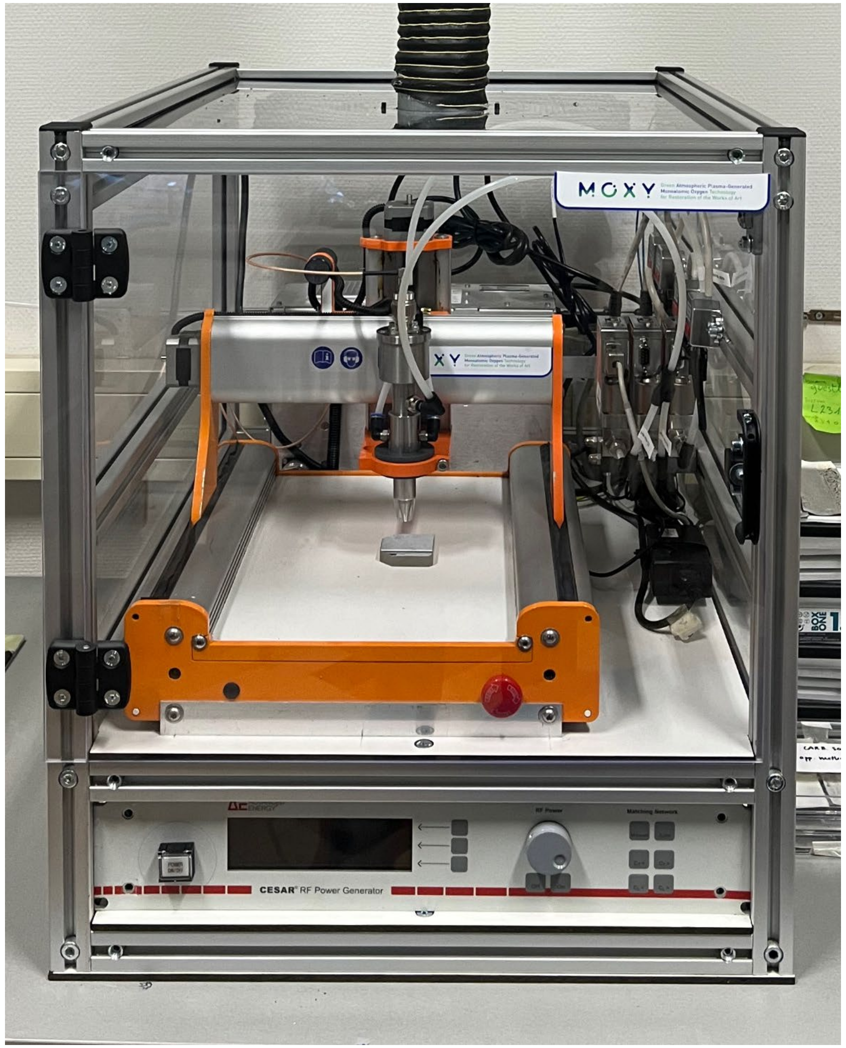


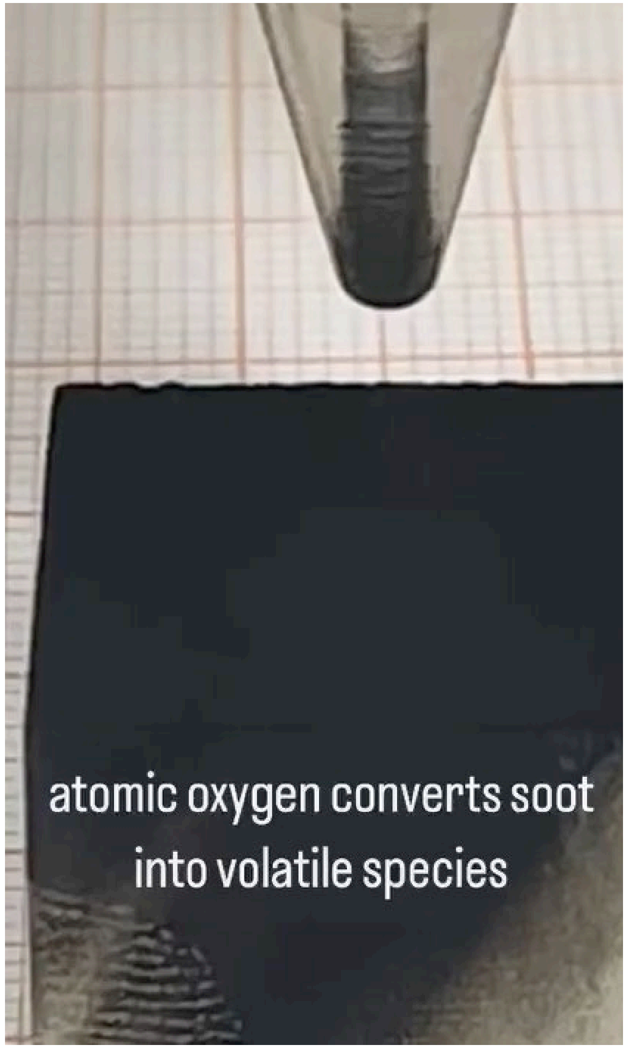
Ghent University's RUPT collaboration with Prof. Aviva Burnstock, Courtauld Institute of Art, Art Conservation, London

Conclusions: AO value for cultural heritage

- **AO provides contactless treatment opportunities for fragile materials that cannot sustain "wet" and "dry" cleaning methods, water, and solvents. It can be applied to a broad range of materials, and it is especially suitable for fire-damaged materials. It is an alternative to traditional environmentally unfriendly methods.**
- **The process can be tailored**, but there are limitations regarding the temperature, as temperature is connected to oxidation reactions.
- **Safe for health and the environment:** AO will reduce the carbon footprint of treatments, waste, and reliance on chemicals. Treatment products are environmentally benign.
- **Non-contact and non-liquid:** For friable, mechanically unstable, and/or liquid-sensitive materials. Minimally invasive and non-mechanical. The atomic surface area of contact with volatile species is much less intense than with fluids.
- **Volatile, non-thermal:** It can access contaminants in porous 3D matrixes but will not drive contaminants deeper into the pores.
- **The contactless cleaning method,** using oxygen as a natural element, is culturally accepted by indigenous and world culture communities. This is particularly important as these communities often do not consent to using man-made materials to treat their indigenous material culture, such as rock art and sacred objects. Using a natural element like oxygen respects their cultural values and practices.
- **New material for first responder actions** treating CH objects that suffered from soot and smoke during wildfires and fires.
- **New ways to completely remove soot and biological contaminants**, such as mold, bacteria, and dead fragmented cells, to optimize gel-based cleaning and consolidation by using AO to temporarily make hydrophobic soils and surfaces hydrophilic; potential to remove toxic organic pesticides, such as DDT, from porous substrates, such as wood objects, textiles, books, and leather.

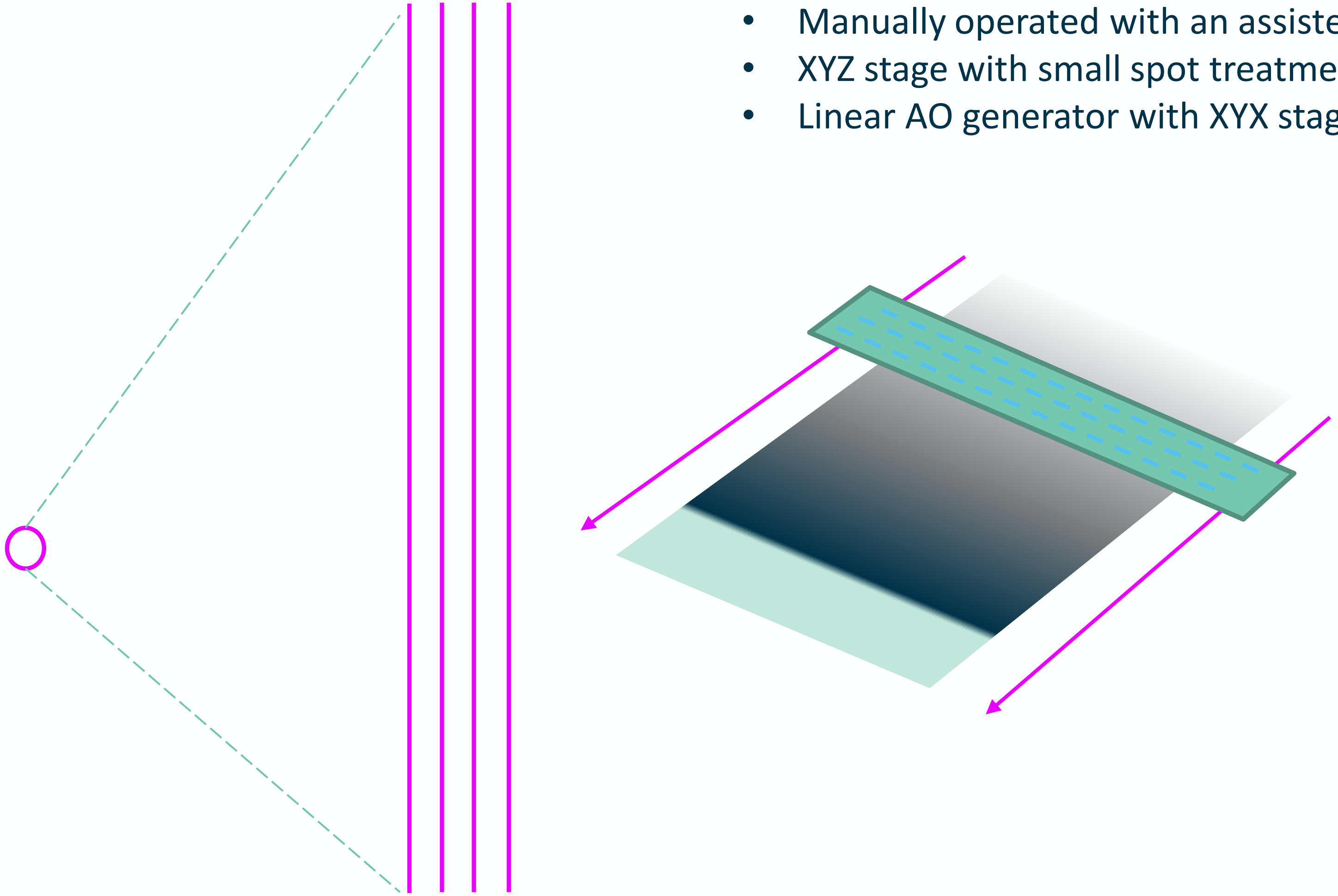
Looking into the future: upscaling AO technology

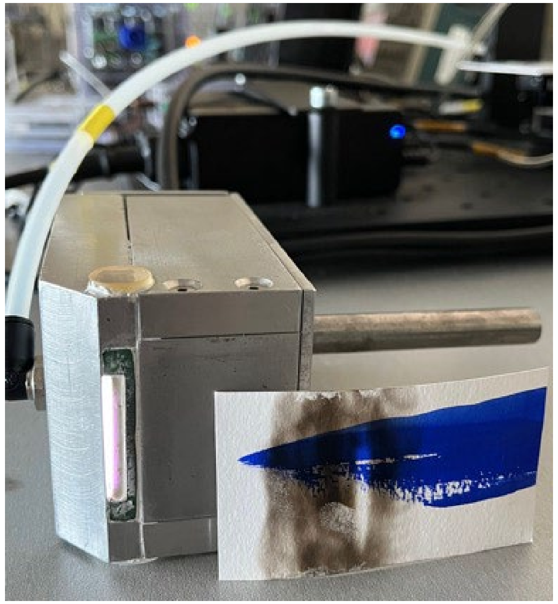




Looking into the future: upscaling AO

- Robotic arm operated
- Manually operated with an assisted mechanical arm
- XYZ stage with small spot treatment area
- Linear AO generator with XYX stage





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Integrated space and green conservation solutions to save and restore humanity's cultural heritage assets from fire-born disasters

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WP2 Fire disaster monitoring and forecast using Earth Observation and AI technologies
WP3 Fire disaster resilience and response solutions and methodology
WP4 Fire Museum App *FireMapp* app design and prototyping
WP5 Fire disaster remediation, cleaning and stabilization using sustainable and green approaches
WP6 Fire disaster effects on cultural heritage materials
WP7 Fire disaster education
WP8 Communication, dissemination, outreach

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Thank you!

MOXY

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