MOXY project: preliminary investigation of non-contact cleaning of some typical art materials using atomic oxygen

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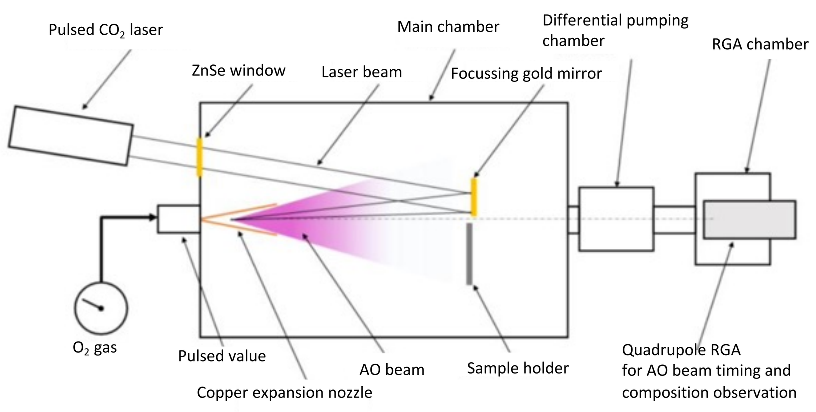
ATOMIC OXYGEN CLEANING TECHNOLOGY

Today, contact-based "wet" and "dry" cleaning methods, using organic solvents/water/gels, are broadly used. However, contact approaches may have limitations when treating fragile and porous materials or sensitive artworks. Non-contact cleaning technologies, in these cases, are highly desirable. The ongoing EU-funded MOXY project [1] has embarked on a mission to develop a non-contact cleaning methodology based on atomic oxygen (AO), generated by non-thermal plasma at ambient pressure, to remove carbon-based contaminants.

PRELIMINARY CLEANING EXPERIMENTS @ESA

As a preliminary study, 39 mock-ups were produced using a range of artistic supports and media (plaster, limestone, canvas, paper, acrylic, oil paint, and pastel). Mock-ups were exposed to AO using the low Earth orbit oxygen environment simulator LEOX at the European Space Agency (ESA). The system operates at low-pressure and uses laser detonation to produce an effluent of atomic oxygen at 99%, which is directed to the sample holder. In this set-up, the exposure time was selected 3.18, 14, 20.7, 46.5, and 54.9 hours. Samples were regularly checked, and those which appeared clean were removed.



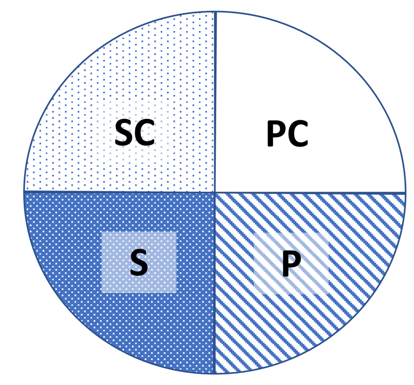
Scheme of the non-contact plasma-generated atomic oxygen cleaning process of soot on canvas [2].

An image of soot partially-removed from cotton canvas.

PRELIMINARY ANALYTICAL ASSESSMENT

The samples were intentionally soiled on one side with typical problematic contaminants - soot, synthetic spray paint, ballpoint pen, markers, and lipstick. Half sample was then cleaned, exposing both the soiled and pristine areas to AO. This way, for each mockup, 4 areas were obtained:

SC: soiled , cleaned — P: pristine, uncleaned
PC: pristine, cleaned — S: soiled, uncleaned



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 color differences and changes in the spectral features; scanning electron microscopy (SEM) and confocal laser microprofilometry (CLM) to evaluate changes in the surface morphology; analytical pyrolysis coupled with gas chromatography and mass spectrometry (Py-GC-MS) to gain insights into molecular effects.

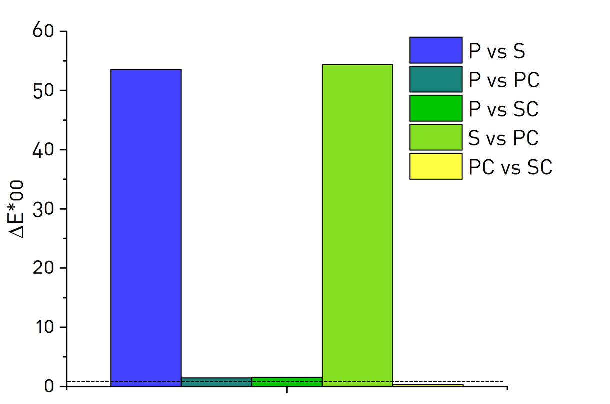
PRELIMINARY RESULTS

#	Substrate	Contaminant	Fluence (At/cm^2)	Flux (At/cm^2·sec)	Exposure to AO (hours)	Analytical assessment
S11	Plaster (gypsum)	Soot	1.84E+20	3.67E+15	14	Spectrocolorimetry, reflectance spectroscopy, CLM
S16	Sandstone	Soot	3.62E+20	7.21E+15	14	Spectrocolorymetry, reflectance spectroscopy
S19	Titanium White acrylic on canvas	Soot	5.01E+20	2.99E+15	47	Spectrocolorymetry, Py-GC-MS

INORGANIC SUBSTRATES

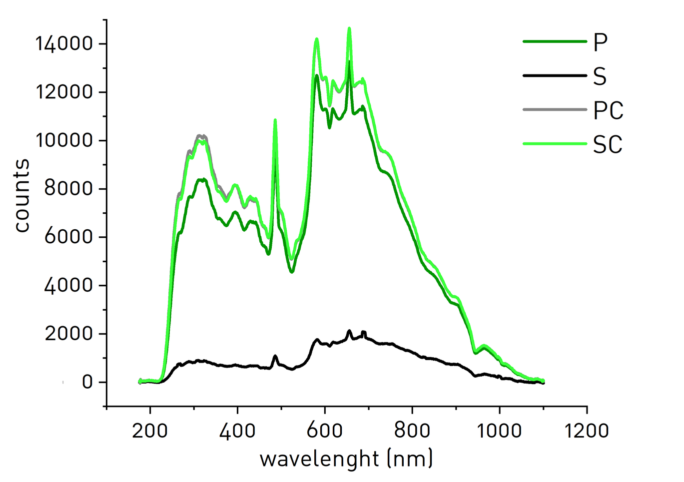
plaster

Spectrocolorimetry

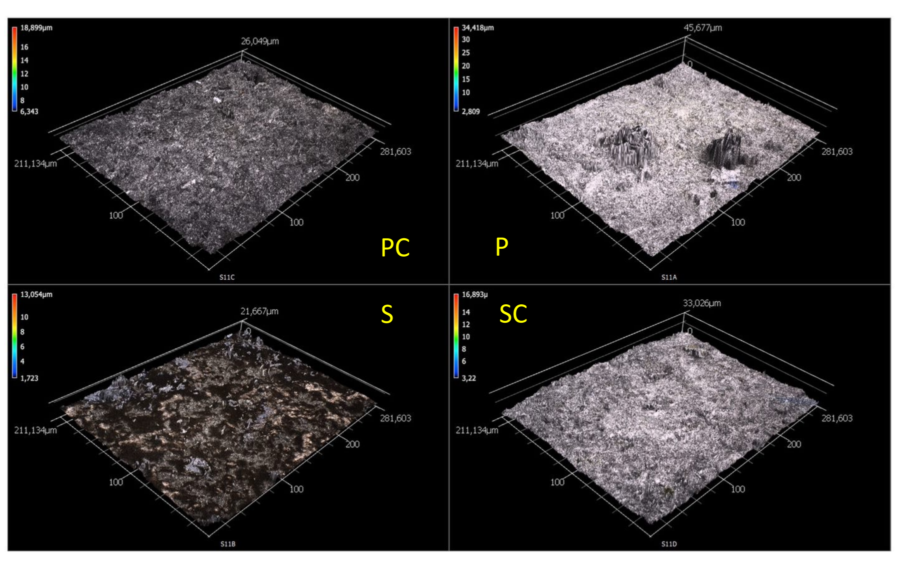


The ΔE^*_{00} between the pristine and cleaned (P vs PC) was around perceivable value by the eye (ΔE^*_{00} = 1) [3].

Reflectance Spectroscopy



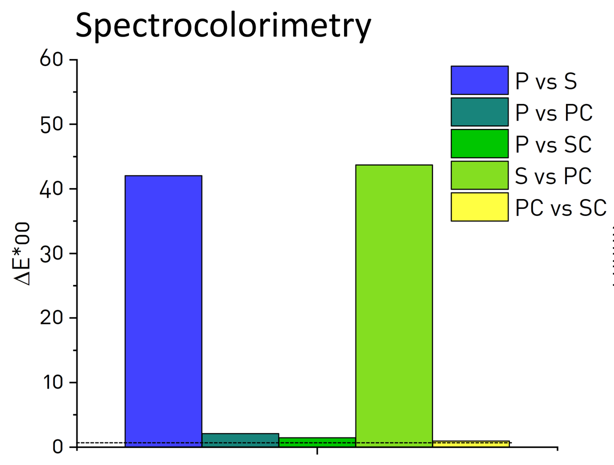
Confocal Laser Microprofilometry (CLM)



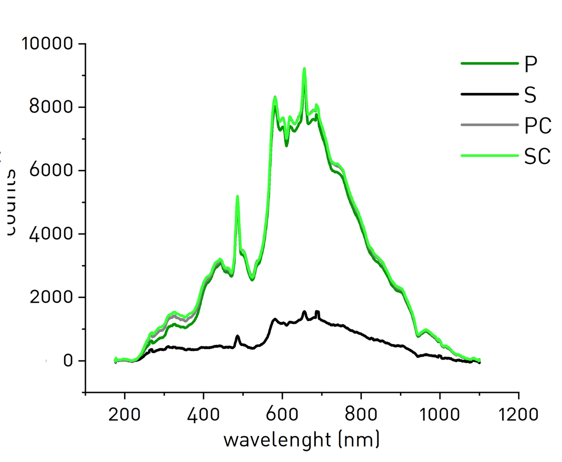
Reflectance spectroscopy showed that the spectra of the cleaned area (PC - grey), pristine (P - dark green), and the pristine/AO treated (SC - light green) that nearly coincide, indicating an effective cleaning. Micro-roughness was assessed using CLM by calculating the RΔq value, which indicates the root mean square of the local tilt dZ/dX along the sampling length. The RΔq in the pristine, uncleaned (P) measured 1.150, and the soiled, cleaned (SC) was similar (RΔq 1.650), indicating that AO did not affect the micro-roughness.

sandstone

Spectrocolorimetry

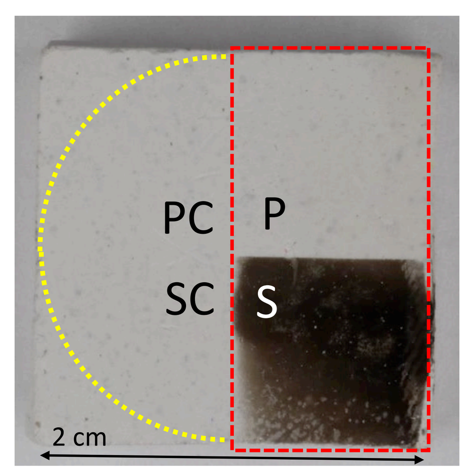


Reflectance Spectroscopy



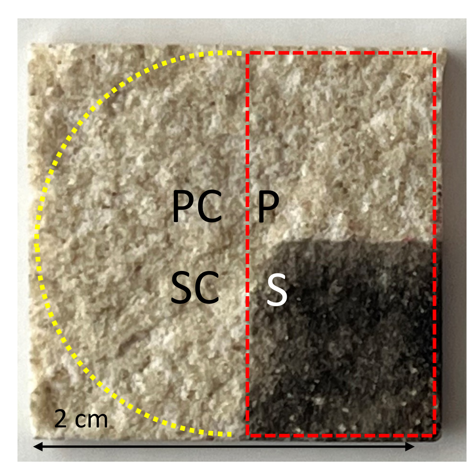
The ΔE^*_{00} between the pristine and cleaned (P vs SC) was around the perceivable value by the eye [3].
The comparison among reflectance spectra indicates an effective cleaning.

S11



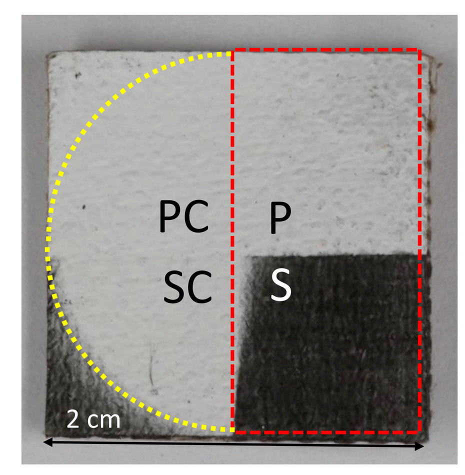
plaster / soot

S16



sandstone / soot

S19

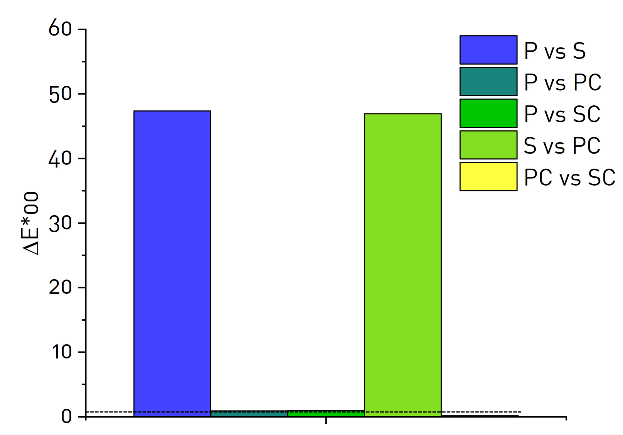


acrylic paint / soot

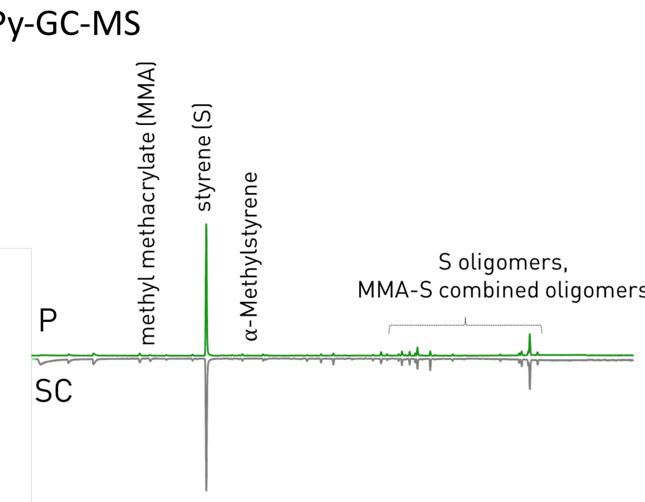
ORGANIC SUB.

acrylic paint

Spectrocolorimetry



Py-GC-MS

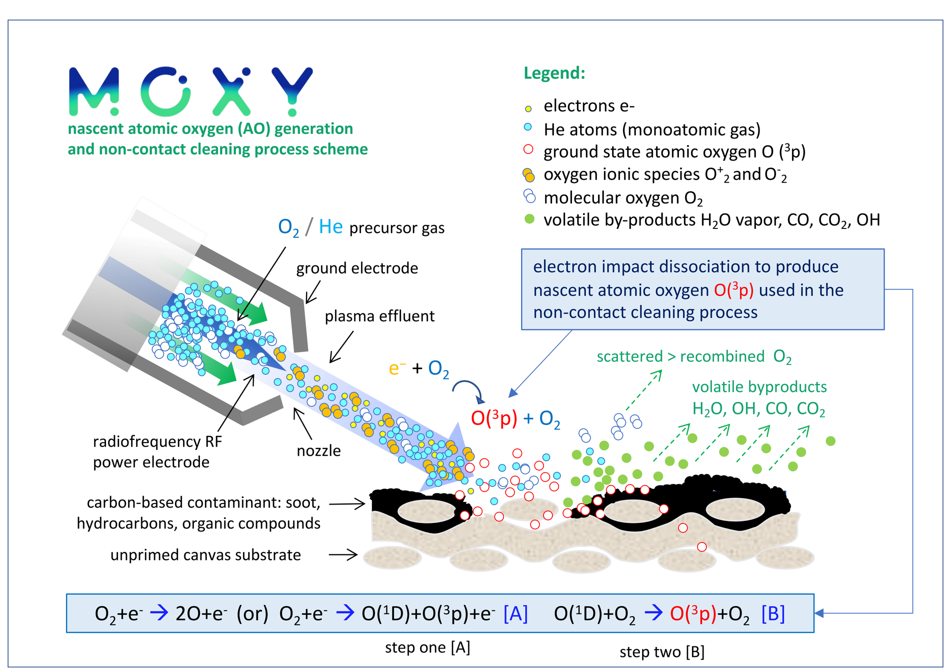


The ΔE^*_{00} between the pristine and cleaned (P vs PC) was around the value perceivable by the eye [3]. Py-GC-MS showed that AO did not affect the chemistry of the acrylic binder of the cleaned area.

CONCLUSIONS

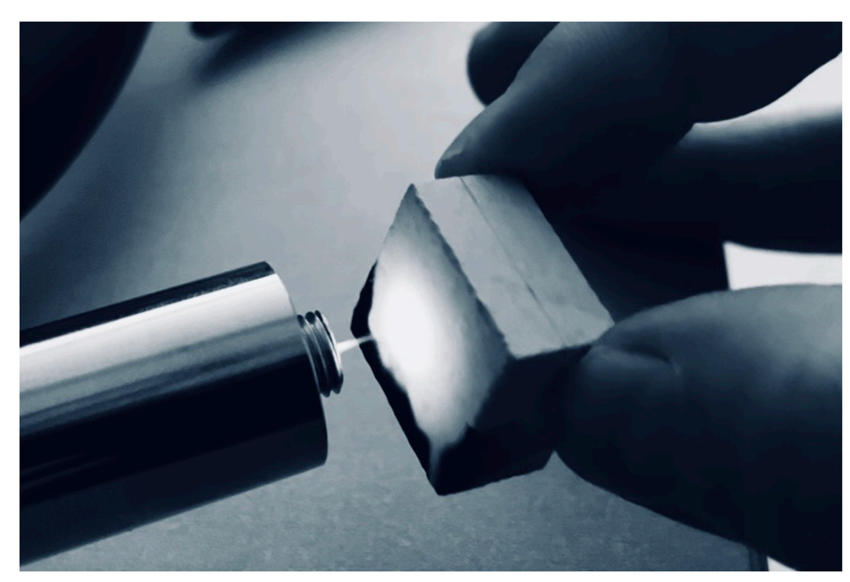
The results obtained from this preliminary study are very promising since contaminants are successfully removed from the substrates, in particular, soot was removed from plaster, sandstone and acrylic paint. In this context, a crucial aspect revealed by this study is the fact that the assessment of the cleaning efficiency and the effect of AO on the substrate is not straightforward due to the contact-less and solvent-less nature of the cleaning method. In contact and solvent/gel-based methods, it is often necessary to evaluate the presence of residues on the artwork surface or the degree of diffusion of solvents used for cleaning. Differently from the contact methods, for the AO-cleaning, this is not necessary, but the possible effects of atomic oxygen on the artwork itself need to be investigated in depth. This calls for new cleaning assessment protocols to be combined with traditional approaches.

MOXY project



In the next steps, we will build on these results and fully exploit the possibilities of the newly built AO. In contrast with the setup used in the preliminary investigations, the MOXY prototype, dedicated to cultural heritage application, will allow to carefully optimize operational parameters such as AO fluence, flux and exposure time, which are key to maximize cleaning efficiency while reducing potential impact on the substrate.

To achieve the target high AO fluencies around 10^{21} m^{-3}, AO is formed by flowing O_2 in He (0.1-10 v.% O_2), using RF field at 13.56 MHz, pulsed modulated RF field at the frequency range 2-100 MHz, which is a different process from the DC arc used by NASA in the 1990' [4] and ESA LEOX facility. In the MOXY prototype, high fluency of AO is produced by electron impact dissociation splitting molecular oxygen into the excited $O(^1D)$ and ground state oxygen $O(^3p)$, which, first forms the excited state oxygen $O(^1D)$ *[A]* and O_2, and then $O(^3p)$ and O_2 *[B]*. A pulsed modulated RF field allows to contain the temperature of the effluent at safe low values, between room temperature and 45 °C.



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References:
[1] 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.
(2)T. Markevicius, I. Bonaduce, A. Nikiforov, N. Olsson, P. Rasmussen, A. Suliga. Nascent oxygen: green atmospheric plasma-generated monoatomic oxygen for contactless and chemicals-free cleaning of works of art. ICOM-CC2023. Accepted manuscript.
(3) 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.(PNNL), Richland, WA (United States).
[4] 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 Triennial ICOM-CC Meeting, 1999, NASA/TM-1999-209411

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