Position paper
Laser Science for Cultural Heritage

The Laser Science for Cultural Heritage Expert Group unites leading specialists across the Laserlab-Europe network with a shared mission: to advance the use of laser-based science in understanding, conserving, and preserving cultural heritage. By leveraging the unique capabilities of Laserlab-Europe's state-of-the-art facilities, the group provides expertise in non-invasive analytical, diagnostic, and conservation methodologies that support museums, conservators, archaeologists, and the wider cultural heritage community. Aligned with the broader Laserlab-Europe mission of fostering excellence in laser-based research, this group aims to develop innovative approaches, support interdisciplinary collaboration, and enhance access to advanced technologies for cultural heritage studies.

Aims and Mission

Our mission is to drive innovation, collaboration, and knowledge transfer in the application of laser science to cultural heritage. The expert group focuses on:

- Developing and validating advanced laser-based methodologies for cultural heritage analysis and conservation.
- Promoting safe, evidence-based application of laser technologies on delicate and irreplaceable cultural objects.
- Facilitating access to specialized research infrastructures within the Laserlab-Europe AISBL.
- Strengthening interdisciplinary networks and contributing to European research strategies.

Scientific and Technical Expertise

The group's combined expertise covers a wide spectrum of laser-based techniques used for material investigation bringing together unique complementary laser-based methods that support the study, diagnosis, and preservation of cultural heritage.

These include **non-invasive structural diagnostics**, such as Digital Holographic Speckle Pattern Interferometry, which is used to assess subsurface layers, internal defects, and the overall condition of objects such as icons and wall paintings.[1–3] **Controlled laser cleaning techniques** enable the safe removal of pollutants or aged coatings from artworks and monuments while preserving underlying materials. We also contribute to understanding laser–matter interactions to ensure safe use of radiation on sensitive cultural objects, developing strategies that minimize potential damage and understanding main composition[4] and aging degradation pathway[5]. **Time-resolved photoluminescence spectroscopy, microscopy and imaging** allow the in-depth photo-physical study of artistic materials with reference to inorganic pigments. The analysis of the spectral and decay kinetic properties of the optical emission related to bulk and surface defects in the crystalline matrix of pigments has shown to be effective for material identification, investigation of pigment and paint reactivity in relation to degradation phenomena, the characterization of impurities, and the inference of information on material synthesis[6–8]. Illustrative examples on the use of these methods in the recent past include the study of pigments and paints based on cadmium yellow[9], zinc white[10], titanium white[11,12], and Egyptian blue[13]. In addition, **advanced analytical tools**, UV-Vis-NIR spectroscopy, hyperspectral imaging[14], XRF[15], Raman[16–18], LIBS[19], Non-Linear Optical Microscopy[20,21], and Photoacoustic Spectroscopy[22,23], allow detailed and in depth chemical and structural characterization of pigments, binders, degradation products, and hidden features[15]. Other types of analysis include characterising works of art using different time-resolved techniques (including FLIM and TAM microscopy) and steady-state fluorescence techniques (including microspectrofluorimetry), which are applied to organic compounds and lakes[24,25] and of historical dyes[26,27], using different analytical and photochemical techniques to characterise these colourant molecules in various art objects.

A further line of research concerns the development of innovative **non-invasive instruments**, especially imaging systems, for the study of artworks, including hyperspectral imaging cameras[28] and multimodal imaging and mapping systems[29,30]. Moreover, new **hybrid and portable tools** combining various analytical techniques such as LIBS, LED-Induced Fluorescence and Diffuse Reflectance can lead to a comprehensive characterization of a wide range of objects minimizing intervention on the object, as well as cost and time of analysis[31].

Together, these methodologies provide essential insights for conservation planning and deepen our understanding of historic materials.

Strategic Goals and Activities

Aligned with Laserlab-Europe's broader mission, the Expert Group 'Laser Science for Cultural Heritage' focuses on strengthening the community through joint efforts, improved visibility, education, and collaborative research. We aim to inspire younger generations by contributing to training initiatives, schools, and hands-on activities; enhance clarity and accessibility by collecting and communicating Laserlab-Europe facilities' capabilities; promote networking both within Laserlab-Europe and with external research and technology infrastructures; and showcase case studies and best practices that support users in managing practical challenges such as logistics or handling of objects. Furthermore, the group encourages collaboration and joint access opportunities, while fostering continuous training and engagement through workshops, events, and community-oriented activities.

The Cultural Heritage Expert Group supports Laserlab-Europe's vision by integrating advanced laser science with the pressing needs of heritage conservation. Through shared expertise, coordinated activities, and strong engagement with the broader European research ecosystem, we aim to broaden access, foster innovation, and safeguard cultural heritage for future generations.

Laserlab-Europe AISBL is an international not-for-profit association, bringing together 48 leading laser research infrastructures in 22 European countries. Jointly, they are committed to coordinate operation and R&D efforts in order to facilitate the development of advanced lasers and laser-based technologies, and to promote the efficient utilisation of advanced laser facilities by users from academia and industry. The majority of the members provide open access to their facilities to scientists from all over the world to perform experiments in a large variety of inter-disciplinary research, covering advanced laser science and applications in most domains of research and technology.

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