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SPECTRAL AND COLORIMETRIC MEASUREMENTS FOR CULTURAL HERITAGE

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COSCH WORKING GROUP 4: ANALYSIS AND RESTORATION OF CH SURFACES AND OBJECTS

KEY WORDS: Colour, spectral measurements, cultural heritage, conservation, restoration

ABSTRACT:

In conservation of material cultural heritage, colour changes are symptomatic of the condition of an artefact. Nowadays advanced techniques are available, which make it possible to measure the changes at high resolution and accuracy. Spectral reflectance is an important parameter in assessing the condition and conservation procedures for cultural heritage objects. It has the advantage over digital photography whose limitations include viewing conditions and device response. For example, spectral reflectance may be useful for pigment identification, particularly when a database of frequently used pigments is available. Spectral reflectance is used for physical characterisation, forensic and lighting purposes or others. Spectral reflectance combined with other techniques can provide information about subsurface microstructures. Even in areas where the colours appear similar to the naked eye, the spectral curves can be different owing to metameric effects. Spectral reflectance provides a lighting designer with essential information on how the visible radiation may damage a work of art, and also about how it will be perceived. The paper presents a methodology for establishing the spectral characteristics of artworks through spectral reflectance and how this information has been processed. These analyses were performed on a range of works of art, including Palaeolithic cave paintings, a polychromed medieval sculpture, and modern oil paintings. Each one of these works required a particular configuration of the measurement system.

1. INTRODUCTION

1.1 Spectral and colour data

The conservation of material cultural heritage and access to works of art raise two major issues. On the one hand, it is necessary to exhibit the cultural heritage which is the historical patrimony of a country and show it to the public. This requires proper lighting in order to enable an adequate perception of cultural objects. On the other hand, adequate conservation requires minimising the interaction of the artwork with electromagnetic radiation to minimise any potential damage.

Europe has important cultural heritage and therefore museums and heritage institutions have a duty of care to preserve it. At the same time, it is absolutely necessary to exhibit this patrimony for the enjoyment of citizens. Conservation and public display require conditions that are often conflicting. Exposure to light gradually causes permanent damage to many artefacts. When an object, whether opaque or transparent, is illuminated, a part of the radiant energy is absorbed. In this radiation-matter interaction two different processes are present which can cause the degradation of museum objects: radiant heating and photochemical action.

Spectral data can help the restorer to assess the tasks and techniques to be applied; for example, as an assisting tool for pigment recognition (Bacci, 2009); particularly when a database of the materials used by the artist, or in the art period is available (Zhao, 2005a) (Zhao, 2005b). Spectral reflectance is used in physical or chemical studies, or by lighting designers (Berns, 2011), (Zhao 2007) mainly when it is necessary to assess stability under light source changes (Staniforth, 1985) (Berns, 2005). Alongside other techniques, it can provide information about microstructures in the coats of paint (Lange, 2011).

Spectral reflectance and the colorimetric calculations have been successfully used to ensure the best possible work in the restoration field. The application of these techniques to material cultural heritage in the examination phase, and in the course of treatment, provides the restorer with very important information. It helps to evaluate the behaviour of the original or added materials which can be found in the work of art both before and after the restoration.

The present discussion is organised as follows: in next section the spectral reflectance methodology is introduced; Section 3 describes the applications of this methodology to several works of art, and finally, conclusions are presented in Section 4.

1.2 Colour&Light UCM/UPM Group

The Colour&Light UCM/UPM Group was established at the Complutense University in Madrid in 2002 (http://portal.ucm.es/web/iluminacionycolor/inicio). It focuses on optics applied to industry, in particular lighting and signalling with LED and daylight devices. From the start most of the work was oriented towards cultural heritage. The group has collaborated with Spanish institutions including the Spanish Cultural Heritage Institute, Reina Sofia Museum and Cantabrian cultural authorities. The present paper is concerned with a selection of projects: the Palaeolithic paintings in the caves of Altamira and the Baths in Cantabria, the Romanesque doorway to the Cathedral of Santiago de Compostella known as the Pórtico de la Gloria (Gate of Glory), and two oil paintings by Pablo Picasso, *The Woman in Blue* (1901) and *Guernica* (1937) both in Madrid, the Centro de la Reina Sofía, are discussed.

2. APPLICATION TO WORKS OF ART

2.1 Rock Paintings

The work described here explores the problems which arise when illuminating Paleolithic cave paintings. We carried out the spectral and colorimetric characterisation of some paintings located in the Murciélagos (bats) cave near Zuheros, Córdoba, Spain. It is one of the most important sites in Andalucia, being the first one in which the art of the Upper Paleolithic appears (http://www.zuheros.es/cueva-de-los-murcielagos). Another is the Castle cave in Cantabria which has been inscribed in the UNESCO World Heritage List (http://cuevas.culturadecantabria.com/castillo.asp).

From this characterisation, the chromatic changes occuring under different lighting conditions are analysed, and the damage function is also computed for the different illuminants used. From the results obtained, an illuminant is proposed whose spectral distribution diminishes the damage by minimizing the absorption of radiation and optimises the colour perception of the paintings in this cave.

2.1.1 Spectral Reflectance of Rock Paintings

Spectral reflectance of the pigment has been measured in four different zones of the painting. The average curve will be denoted in the following as $\rho_p(\lambda)$. The spectral reflectance, $\rho_r(\lambda)$, of the wall in the surrounding of the painting has also been measured in absence of pigments (rock). These measurements have been performed using an AvaSpec-2048-2 spectrophotometer in the spectral range from 400 to 750 nm with a step of 5 nm.

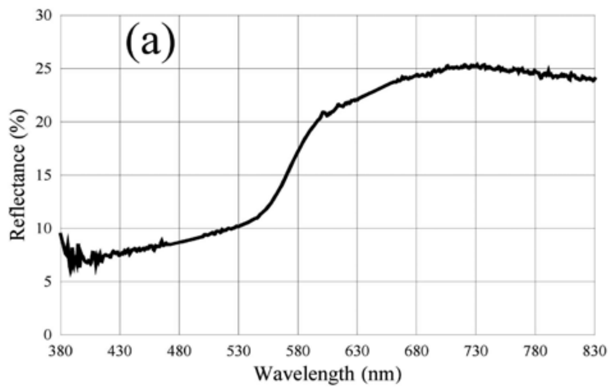

Figure 1. Spectral reflectance of rock paint in the Cave of the Baths (Zhueros, Spain).

In order to develop the calculation a torch was defined as the lighting source used by the original artists, in such a way that it is considered that proper colour reproduction is obtained when the painting is illuminated with the spectral radiant distribution of a blackbody radiator at temperature T_t=1850º K. With this information the chromatic coordinates of the paint and rock can be defined. In this specific case the object of the work can be analysed from a different point of view: If the perception of the drawing is important it requires a high chromatic distance between rock and paint chromatic coordinates. However, if the original perception is simulated (as plausibly seen by the artist), the distance between coordinates at 1850ºK and source light must be minimal. In order to quantitatively compute the differences between the colour stimulus, obtained when the painting and rock are illuminated with a torch, and also when a different source of light is used, all the colour stimuli specified in the CIE 1931 system have been transformed to the CIELAB colour space. Up to 40 different standard light sources were calculated.

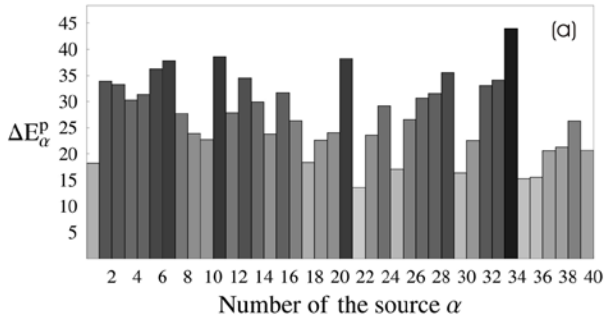

Figure 2. Colour distance (CIELab) of rock paint for 40 standard light sources regarding the torch.

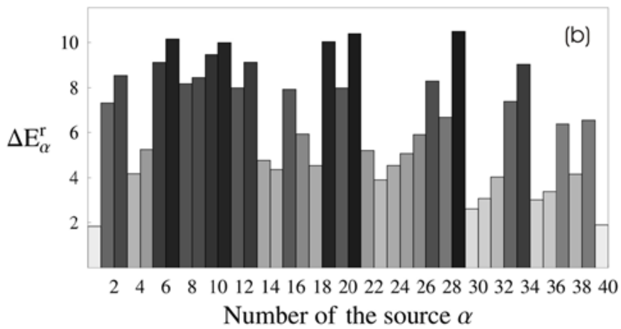

Figure 3. Colour distance (CIELab) of rock for 40 standard light sources regarding the torch.

2.1.2 Damage Estimation

In order to calculate the most adequate spectral distribution of the light source it is necessary to evaluate the damage. In this work the damage factor such as it was defined by CIE has been used (CIT-157 2204)

$$D_{mg} = \int S(\lambda) F(\lambda) d\lambda \qquad (2)$$

where $S(\lambda)$ is the spectral irradiance distribution of the illuminant and

$$F(\lambda) = e^{-b(\lambda - 300)}, \quad (3)$$

is the so-called relative damage factor, where wavelength is in nm and b constant depends on the material.

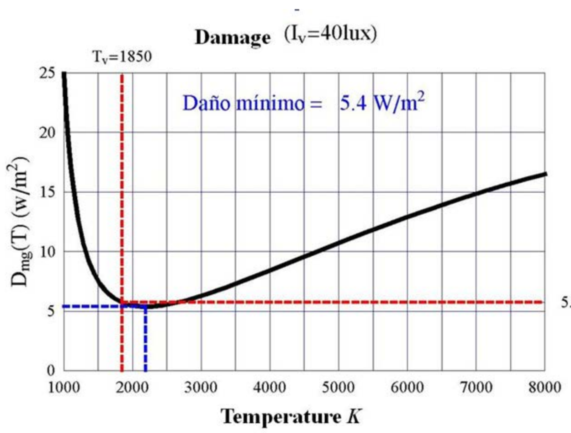

Figure 4. Damage factor as a function of light source temperature.

As has been demonstrated in the previous section the use of a standard illuminant does not give enough flexibility to optimise the lighting design. With the aim to improve the quality of the proposed solution, a LED system with RGB configuration was used. This kind of device has other advantages when it is made with quality production controls such as lifetime, stability and start time. A system with three LEDs — red, green and blue — was used in the present study. It is inexpensive and readily available on the market. In this case it is necessary to define the contribution of each LED, named K_r, K_g and K_r respectively. Three parameters were implemented in the algorithm: the damage D_{mg}, the colour contrast between painting and rock $d_{c\text{-}p}$ (how well can be the drawing perceived) and the distance to the torch illuminant d_a (simmulating how the artist may have seen his work). In the selected algorithm each parameter has to have different weight such as is shown in the next formula.

$$(4) \quad F_2(D_{mg}, d_{c-p}, d_a) = \left(D_{mg}\right)^2 - \left(d_{c-p}\right) + \sqrt{d_a}$$

In this case the damage D_{mg} has the highest weight and the distance to torch illuminant d_a is the smallest. The objective is to minimize the value of this function.

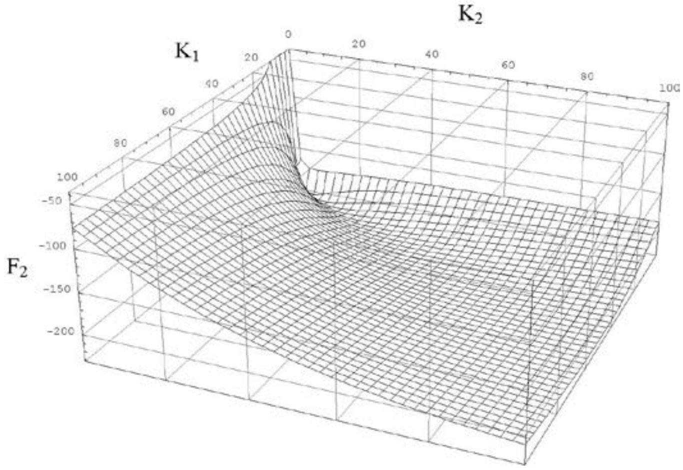

Figure 5. Damage factor as a function of LED factors K_r and K_g.

With these factors for the contribution of each colour LED the spectral distribution of light source can be estimated. It is shown in Figure 6.

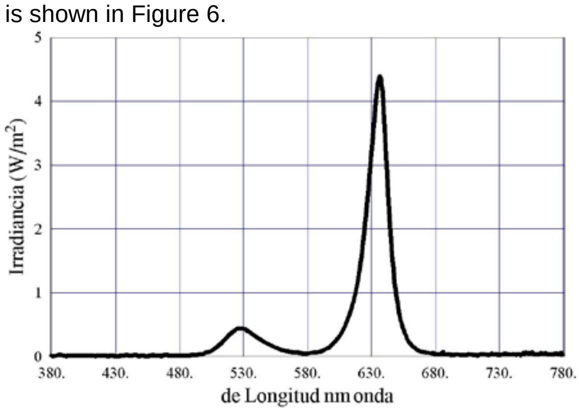

Figure 6. Spectral distribution of the proposed LED light source.

2.2 Gate of Glory in Santiago de Compostela

The west entrance to the cathedral in Santiago de Compostella, from the Obradorio square, leads through the magnificent 12th-century Gate of Glory placed inside a much later structure. In the 18th century, Fernando de Casas Novoa was commissioned to design a new Baroque façade to protect the Romanesque doorway and sculptures, which was constructed by Master Mateo between 1168 and 1188. One of the most important materials used in the design of the Obradoiro façade is the light. When sunlight falls onto the stone sculptures their temperature rises and the surface is dries. Given that the inside of the cathedral is cold and wet, the moisture from inside the cathedral moves towards the sculptures carrying the mineral salts. In order to reduce the effect of solar radiation on the sculptures, but with the aim of maintaining the present view of the medieval doorway and the Baroque façade from Obradoiro square and from inside the building, a neutral multilayer filter with 62% transmittance from 380 to 850, was set up on the outside face of the cathedral’s glass windows.

Figure 7. Sculptures in the Gate of Glory in the cathedral of Santiago de Compostella selected for a thermal study.

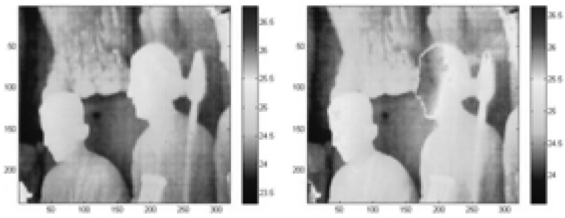

Figure 8. Gradient of temperature in the Gate of Glory.

An evaluation of the cleaning technology (laser, mechanical and chemical) was carried out, to assist the restoration process, by measuring the colour of selected points.

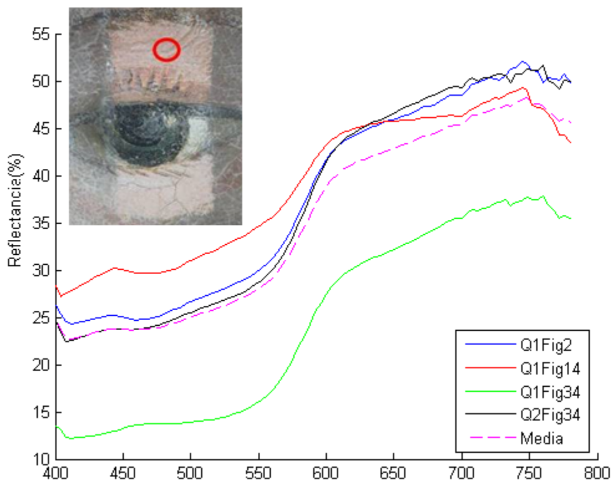

Figure 9. Measured skin spectral reflectance in the Gate of Glory.

These data will be used as a reference in the control of the restoration process. In Figure 9 spectral reflectances of skin areas cleaned chemically are shown. Their Lab coordinates under the *A* illuminant are plotted in Figure 10.

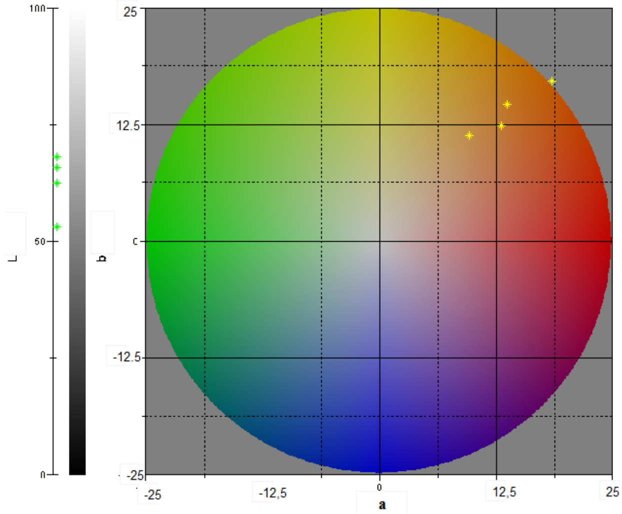

Figure 10. CIELab coordinates of skin in the Gate of Glory.

2.3 *The Woman in Blue*

The methodology for evaluating the results of restoration treatment was also applied to a painting by Picasso titled *The Woman in Blue* in the Centro Reina Sofía, Madrid. This is a picture with an interesting story. According to the Centro’s catalogue (http://www.museoreinasofia.es/en/collection/artwork/mujer-azul-woman-blue), “Having shown the painting at the National Exhibition of Fine Arts in Madrid in 1901 where it received only an honourable mention, Pablo Picasso decided not to pick the painting up when the event closed.” The painting was in need of restoration when it was re-discovered and first restored in the 1940s. The aim of this restoration was to recover the original faithful image. Besides many other analytical techniques, spectral and colorimetric analyses of the painting were carried out in order to evaluate the visible result of the restoration process, and as a tool for monitoring future changes. A 140-point matrix as a control to evaluate the spectral reflectance changes in the restoration process was utilised, alongside a series of specific points out of this general matrix.

The aim of carrying out spectral reflectance measurements is twofold. First, it is a powerful tool to test how the paint behaves over time; second, it allows the evaluation of the perceived effect of the restoration process, because the spectral reflectance is a very important tool to evaluate its visible results.

Figure 11. Location of specific measured points in the *Woman in Blue* (1901) by Pablo Picasso, oil on canvas, Madrid, Centro Reina Sofía.

2.3.1 Local analysis

The lips of the depicted woman are very important and symbolic detail in this picture. The obtained data in this area show how the varnish layer was changing the perceived colour of the paint. In this case colour of the lips was changing the chroma value and the luminance a little, while the hue was the same. The chroma was 37,3 when the paint had the varnish layer and 41 when this layer was taken out.

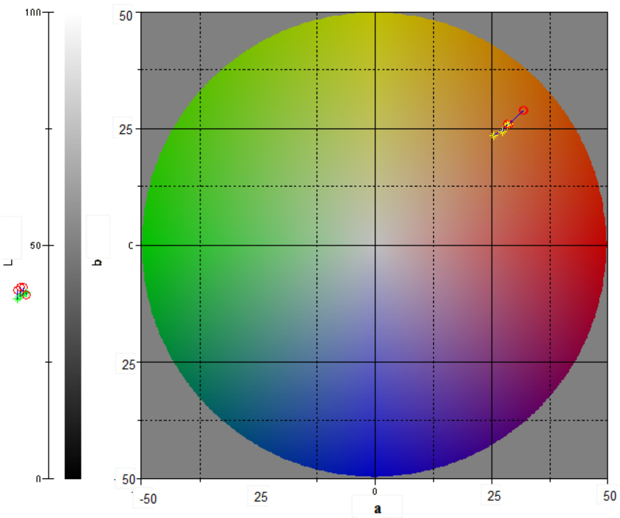

Figure 12. Lab coordinates of the detail in *The Woman in Blue* showing the lips, with ***** and without **o** varnish layer.

2.4 *Guernica*

Programmed spectral reflectance measures can be a very useful tool for conservation of cultural heritage objects. Reflectance studies of paintings can monitor changes over the time through. Spectral measurement of a large painting, such as the *Guernica* by Pablo Picasso (3.5m x 7,8m), is a huge challenge. In preventative conservation the best method is the use of a contact-less spectroradiometer.

A total of 2200 points distributed in an array over the painting were measured. The measurements were taken outside exhibition hours over five nights.
The system used was composed of:

- Contactless spectroradiometer
- Calibrated lighting system
- XYZ magnetic motor
- CCD system for ocular image
- Telemeter
- Controlling software
- Computer

All the hardware was controlled by a computer running Matlab. This math program is “the brain” of the system and controls other processes via a GUI.

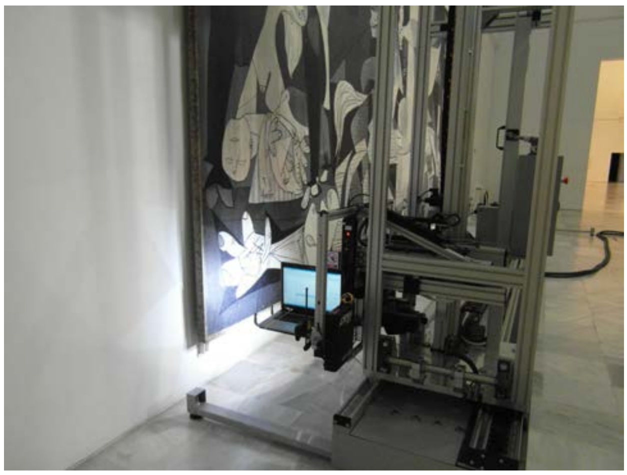

Figure 13. Spectral reflectance measuring robot working on *The Guernica* (1937) by Pablo Picasso, oil on canvas, Madrid, Centro Reina Sofía.

The central computer has to move the spectroradiometer to the calibrated white, then measure spectral radiance and save data. Afterwards, it directs the system to the first row and starts with point 1, measuring the spectral radiance of the point. In this point the Cartesian position of the motor is recorded and also an image of the measured point is registered in the data base.

Figure 14. Graphical measurement location for point *n*. Central black circle is the measured area.

Due to tensions, contraction and expansion of the canvas the XYZ dimensions of a large painting can change over time. For this reason an image of the measured points locates the selected point without any doubt. So the registered image from the spectroradiometer, which includes measured points, assures traceability in the future measurement rounds.

3. CONCLUSIONS

Spectral reflectance methodology is a powerful tool which can be applied to the conservation of material cultural heritage. In this work this technique has been applied to cave paintings, sculpture and used in the analysis of the restoration process of a large easel painting, showing the robustness and flexibility of the methodology. The information obtained may be used not only for registration of the present condition, but also for calculating a specific lighting system. Thus it is possible to design a lighting system that reduces damage caused by the visual radiation when the artwork must be exhibited. Spectral reflectance measures require a level of high optical accuracy and mechanical precision in the positioning system. This implies the necessity of integrating advanced automatic positioning systems within the optical devices used.

4. REFERENCES

Colour&Light Group, Complutense University in Madrid, http://portal.ucm.es/web/iluminacionycolor/inicio (6 Mar. 2014).

M. Bacci, 2009, A study of the blue colours used by Telemaco Signorini (1835–1901), Journal Cultural Heritage, 10, 275–280.

Murcielagos cave, Zuheros, Córdoba, Spain. http://www.zuheros.es/cueva-de-los-murcielagos (6 Mar 2014).

Castle cave, Cantabria, Spain, http://cuevas.culturadecantabria.com/castillo.asp (6 Mar. 2014).

Y. Zhao, 2005a, Improvement of Spectral Imaging by Pigment Mapping, 13th Color Imaging Conference Final Program and Proceedings.

Y. Zhao, 2005b, Using the Matrix R Method for Spectral Image Archives, AIC Color.

R.S. Berns, 2011, Designing White-Light LED Lighting for the Display of Art: A Feasibility Study, Color Res. Appl. 36 No. 5, 324–334.

Y. Zhao, R.S. Berns, 2007, Image-Based Spectral Reflectance Reconstruction Using the Matrix R Method, Color Res. Appl. 32 No. 5, 343–351.

S. Staniforth, 1985, Retouching and color matching: the restorer and metamerism, Studies in Conservation, Vol. 30, No. 3, pp. 101–111.

R.S. Berns, 2004, A retouching palette that minimizes metamerism, ICOM, 2005 ISBN-184407-253-3.

R. Lange, 2011, Optical coherence tomography and spectral imaging of a wall painting, SPIE Newsrooms, 10.1117/2.1201107.003778.

G. Wyszecki, W.S. Stiles, Color Science: Concepts and Methods, Quantitative Data and Formulae, Wiley & Sons, 2000.

CIE-157, 2004: Control of damage to museum objects by optical radiation.

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