Linen Coloration by Pulsed Radiation
A Review

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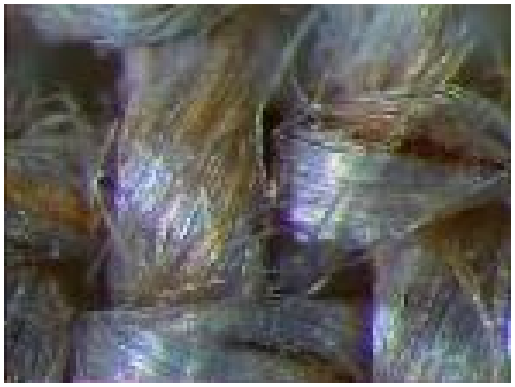

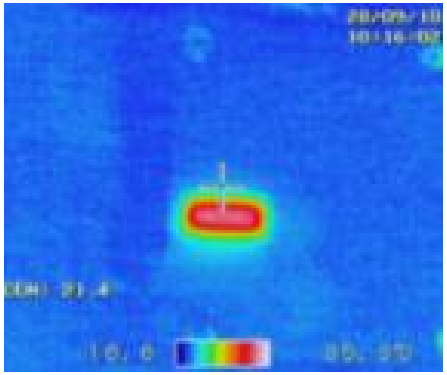

Pasco, July 22, 2017

International Conference on the Shroud of Turin
(ICST-2017)
SEEKING SOLUTIONS TO THE MYSTERIES OF THE SHROUD

Outline

- **Shroud-like linen coloration by radiation: Pre-history**
- **Failure of first radiation-based attempts**
- **Radiation-based coloration, our results**
- **Did media misunderstand scientific results?**
- **A scientific search for God?**
- **Conclusion**

Proposal of Jackson (1990) and rebuttal of Rogers

J.P. Jackson, "***Is the Image on the Shroud Due to a Process Heretofore Unknown to Modern Science?***", Shroud Spectrum International, No. 34, March 1990 pp. 3-29.

UV radiation is suitable to obtain a Shroud-like coloration (shallowness, shade embedding 3-D information, image in linen regions not in contact with the body).

R. Rogers, "***Testing the Jackson 'Theory' of Image Formation***", www.shroud.com/pdfs/rogers6.pdf

"Intense radiation exerts pressure as in a nuclear weapon. Radiation pressure coupled with ablation (the sudden appearance of hot gas, which gives the same propulsive effect as rocket exhaust) of the cloth by intense radiation should have thrown the cloth a considerable distance and probably would have torn it to shreds. **Experiments we did with pulsed ultraviolet lasers on linen resulted in ablation and destructive shock waves. Samples often were converted into a little amorphous powder and gas (…) The surface of the Shroud does not show the effects of radiation.**

Two opposite views. Thesis and antithesis. Where is the synthesis?

J.P. Jackson, K.E. Propp, ***Comments on Rogers' "Testing the Jackson 'Theory' of Image Formation"*** , www.shroud.com/pdfs/jacksonpropp.pdf

"Radiation represents a large category of phenomena that can be described by (1) intensity, (2) wavelength, and (3) event duration. Each of these variables can change by orders of magnitude. The laser experiment cited above represents but one point in this vast three-dimensional parameter space. Clearly, the entire category of radiation cannot be discarded on the basis of one, overly intense, laser experiment that corresponds to a single point in that radiation parameter space"

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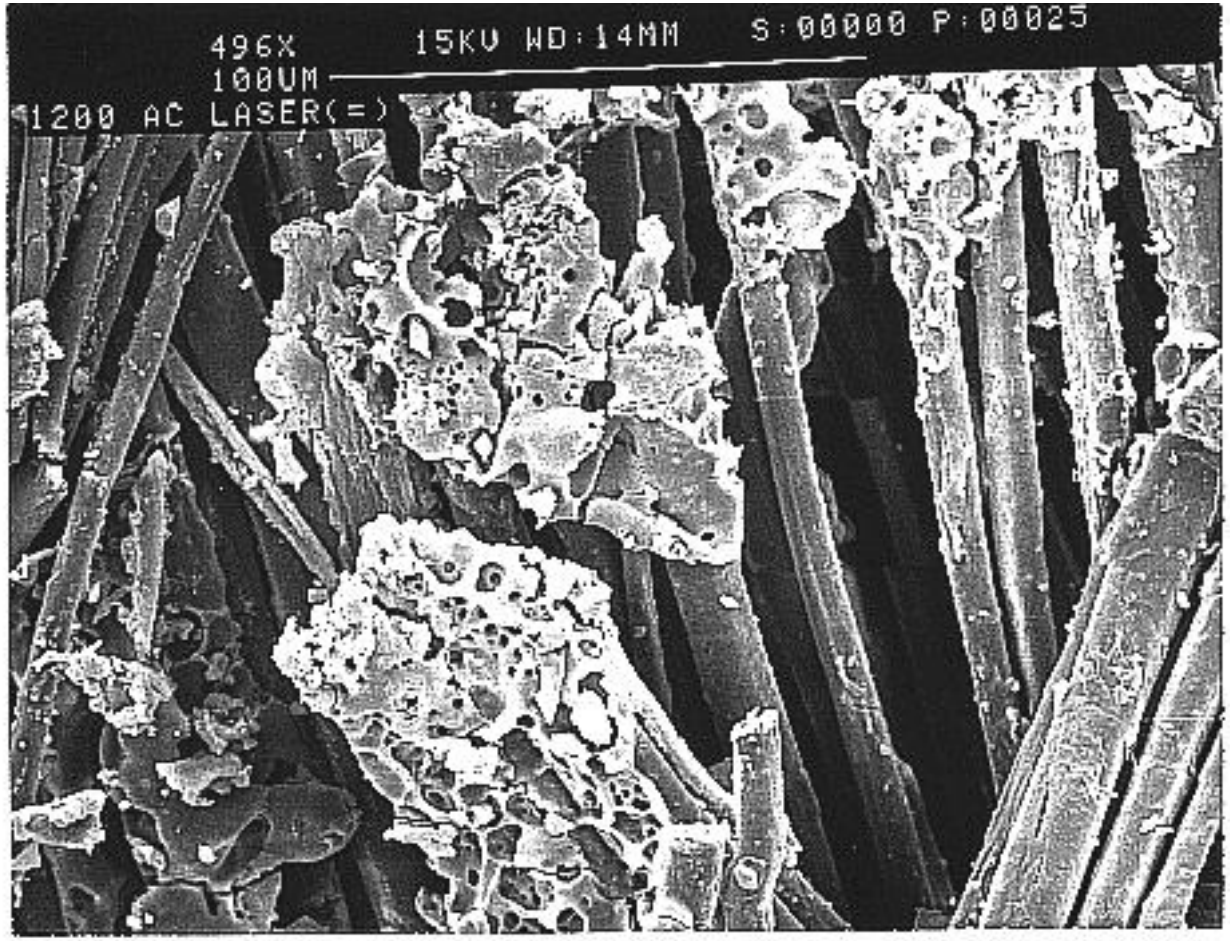
Attempt of Testore et al.

AUTEX Research Journal, Vol. 2, September 2002

- Laser CO_2 (far infrared) and electron beams.
- **Macroscopic results**: brown coloration.
- **Microscopic results**: Fibers are damaged, burnt, vaporized.

Attempt of Testore et al.

AUTEX Research Journal, Vol. 2, September 2002



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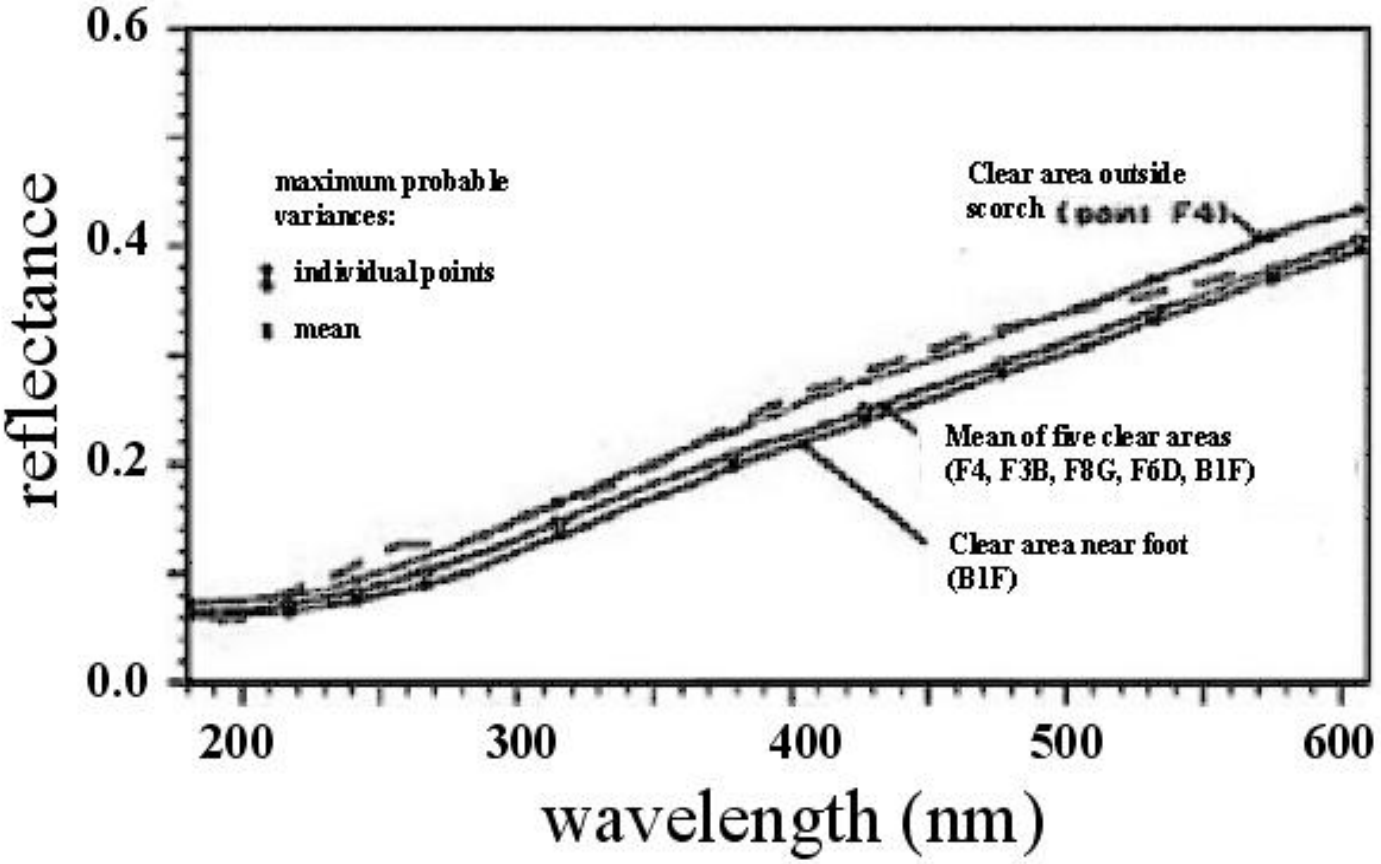
Why photochemistry? Why UV?

Energy carried by short-wavelength radiation breaks chemical bonds of the irradiated material without inducing a significant heating (photochemical reaction).
Moreover, linen has a molar absorptivity which increases when decreasing the radiation wavelength: the smaller the wavelength, the thinner the material absorbing all the radiation.

Then, we have chosen the ultraviolet radiation as an "acting at distance" mechanism to obtain at least three of the main characteristics of the Shroud image: a thin coloration depth, a contactless action and a low-temperature coloration process.

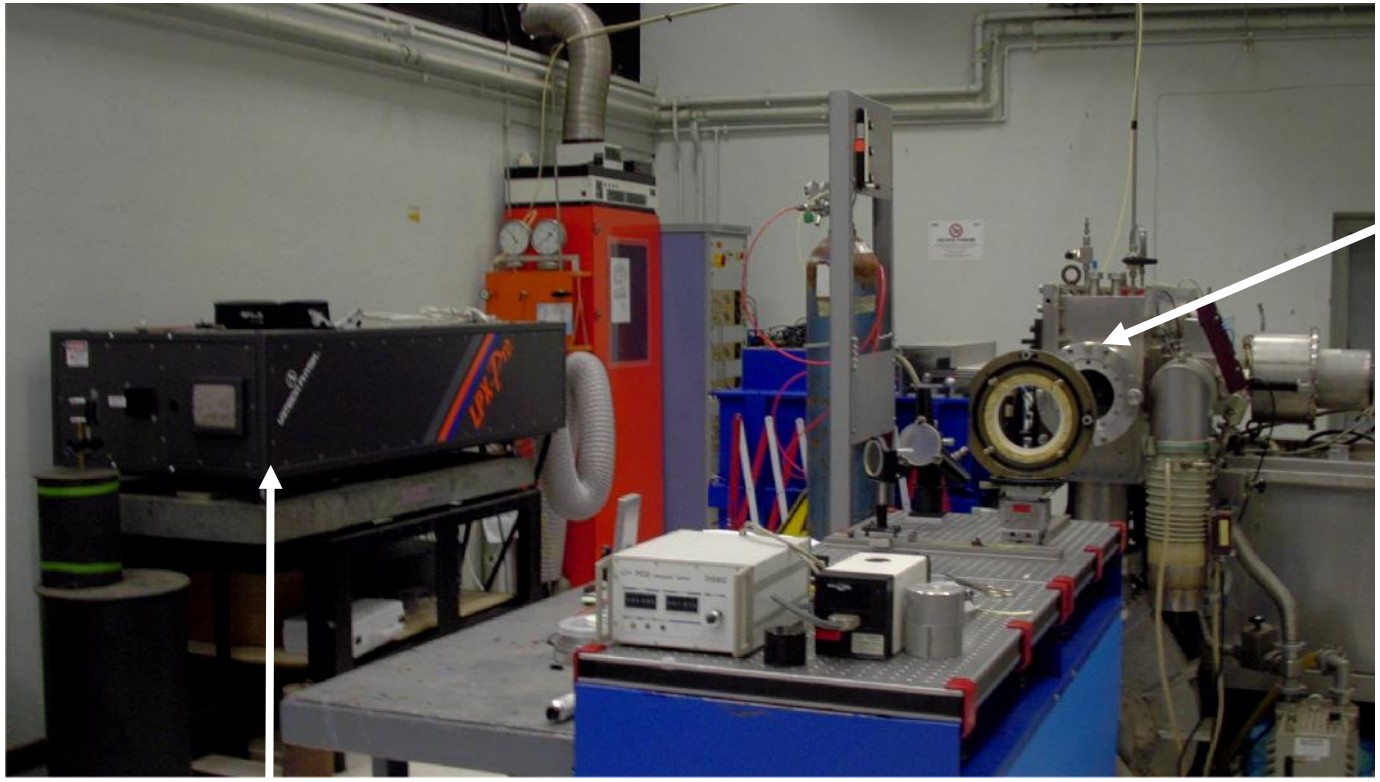
How much different is the linen we used from the Shroud?



The solid lines show the **absolute reflectance** of the linen of the Shroud in areas of no-image as a function of the wavelength (Gilbert, Appl. Opt. 1980).

The dashed line shows the absolute reflectance of the linen used in our experiments. From *J. Imag. Sci. Techn.* ***54,*** *4302 (2010)*

Set-up at ENEA Frascati



Hercules ENEA PBUR

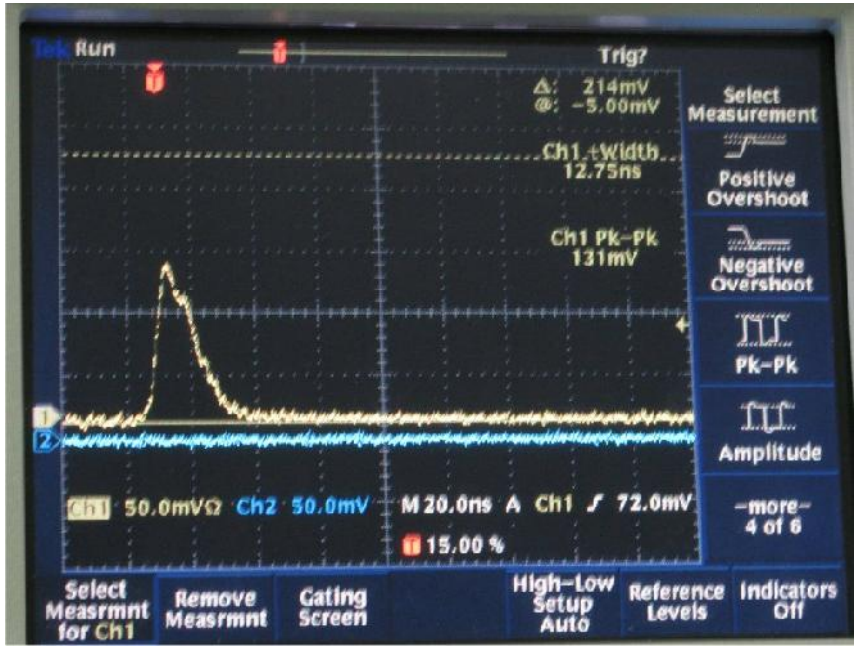
6 J, 120 ns, 5 Hz

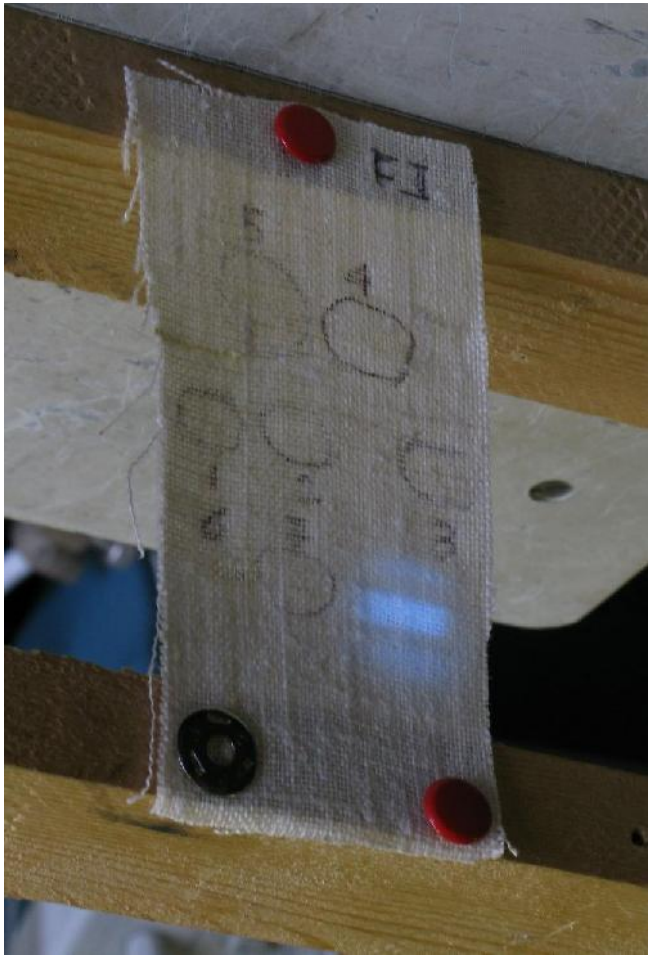
308 nm

LPX-305, PBUR

0.5 J, 30 ns, 50 Hz. 308 nm or 193 nm

Ultrashort UV pulses irradiate linens

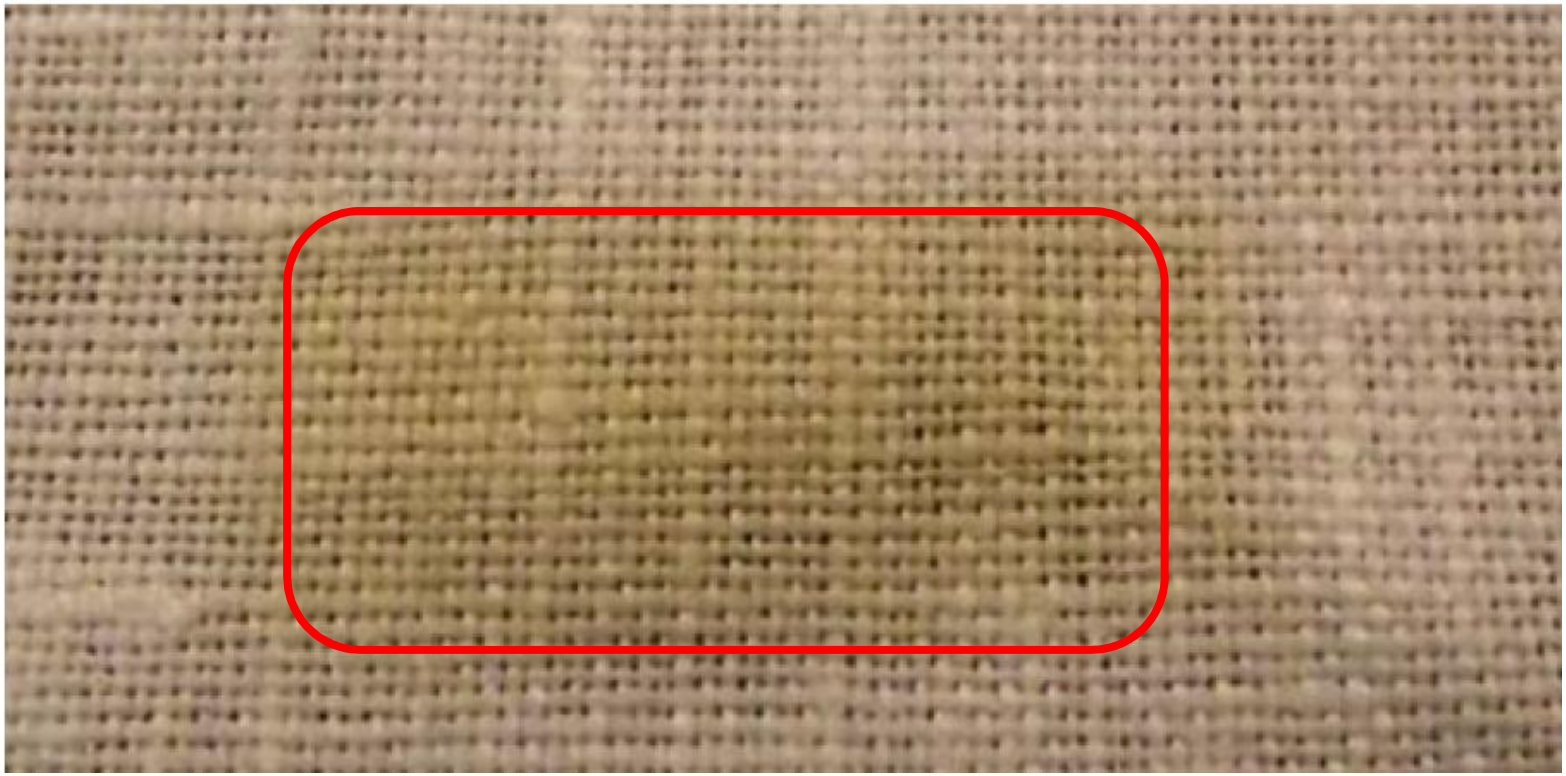




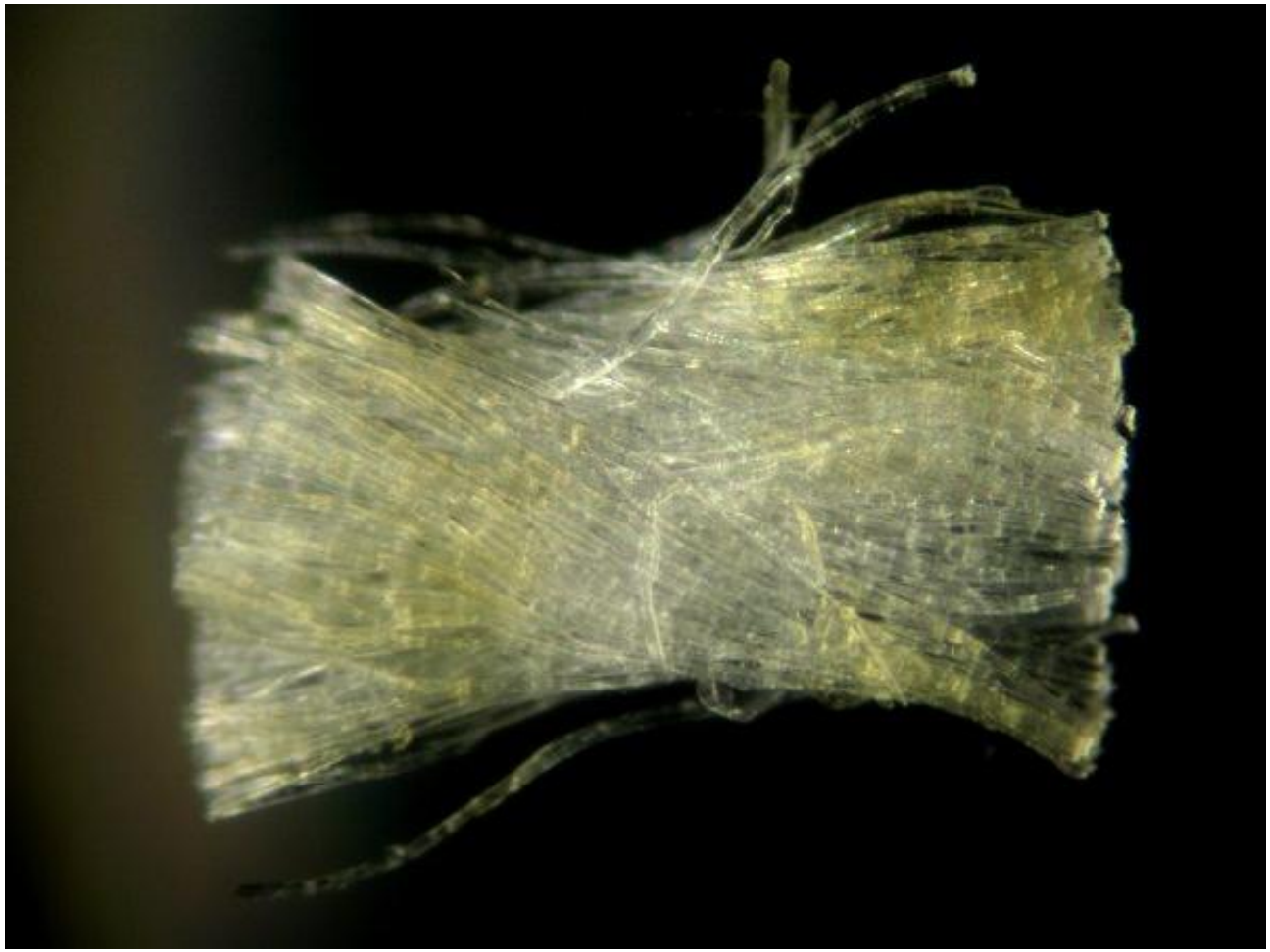
Short movie

Excimer laser irradiation of linen

Raw linen after 10ns, 193nm irradiation



Linen thread after 10ns, 193nm irradiation



From *J. Imag. Science Techn.* ***54,*** *040201 (2010)*

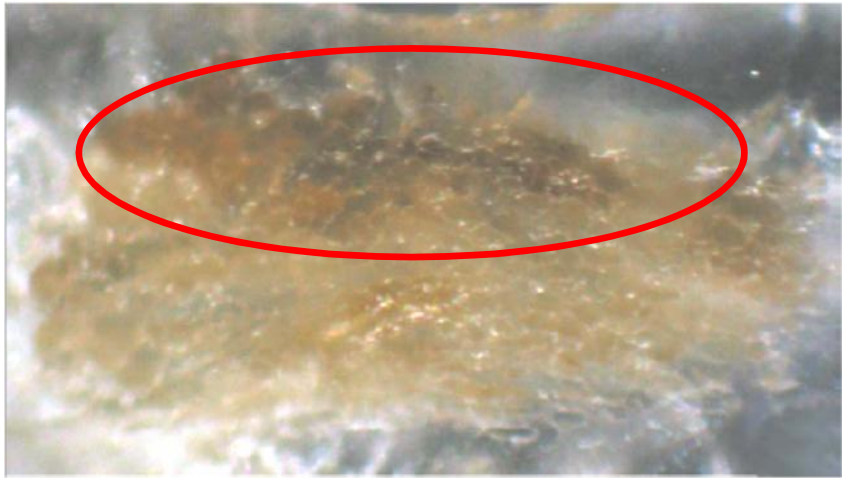
Coloration is a threshold effect in energy density, provided pulsewidth is shorter than 50 ns !!!

Depth of coloration: UV vs. VUV

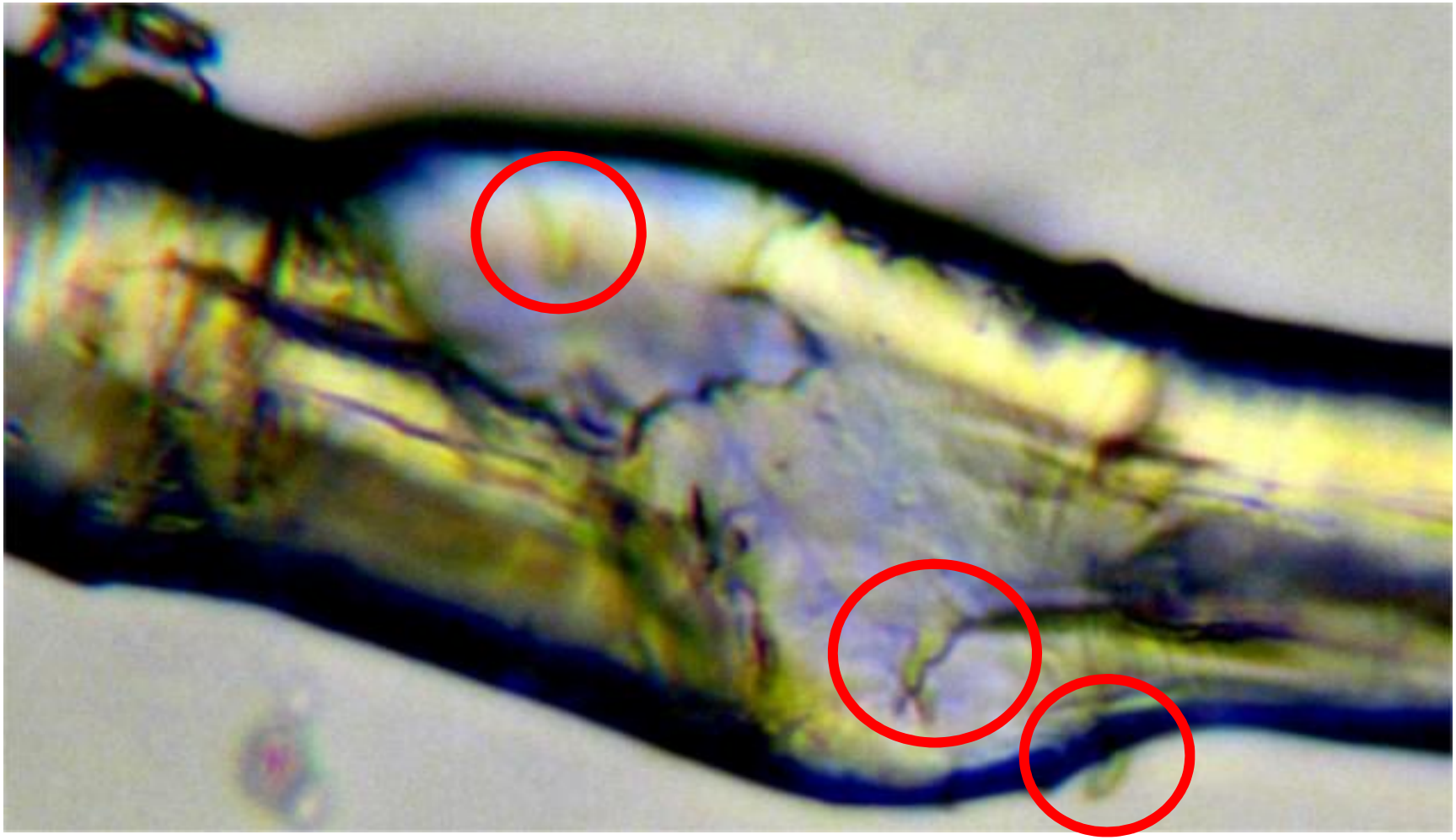
$\lambda = 193$ nm

Cross section of irradiated linen threads

$\lambda = 308$ nm

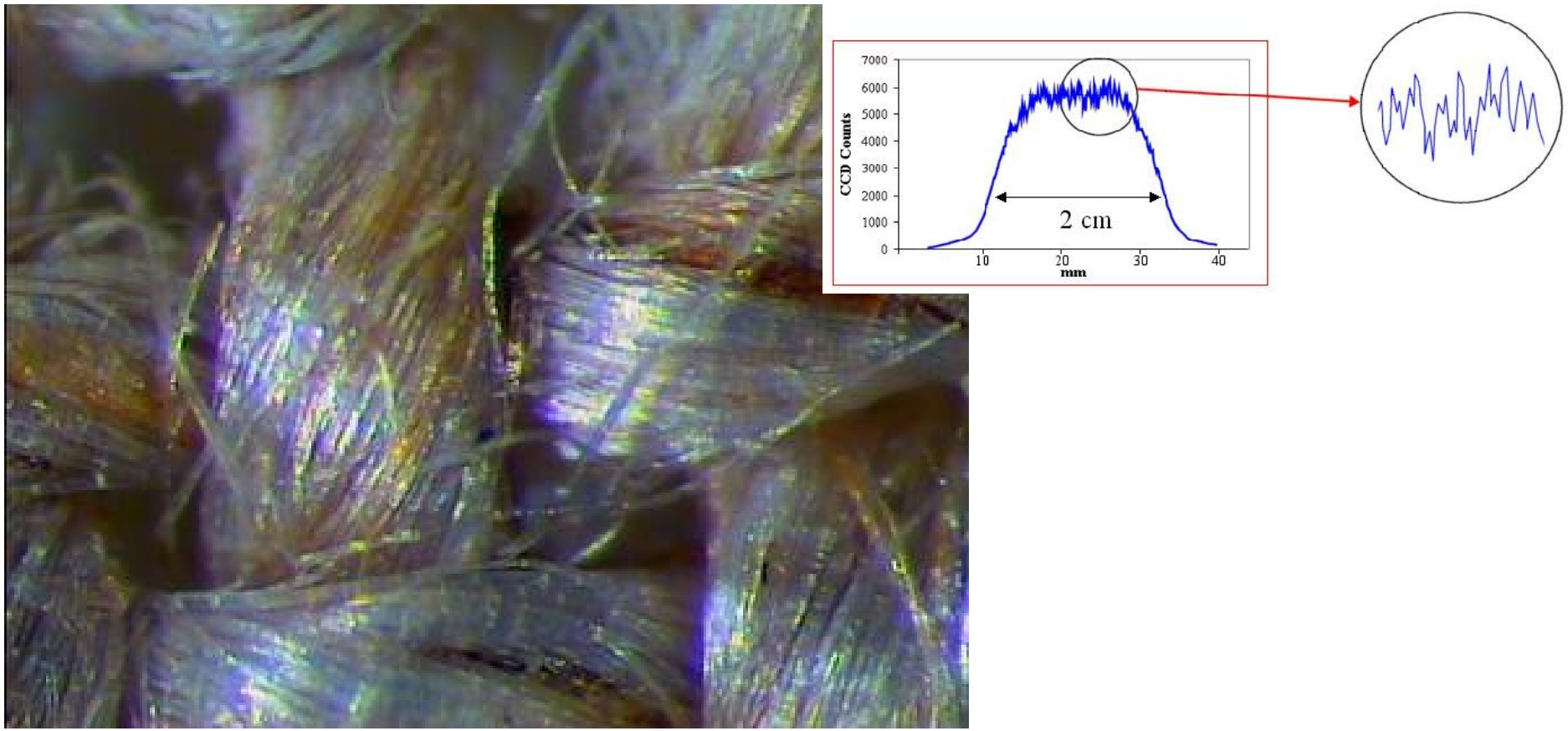


After VUV irradiation, few fibres show a coloration limited to the external 200 nm thick primary cell wall



From *Applied Optics* ***51***, *8567 (2012)*

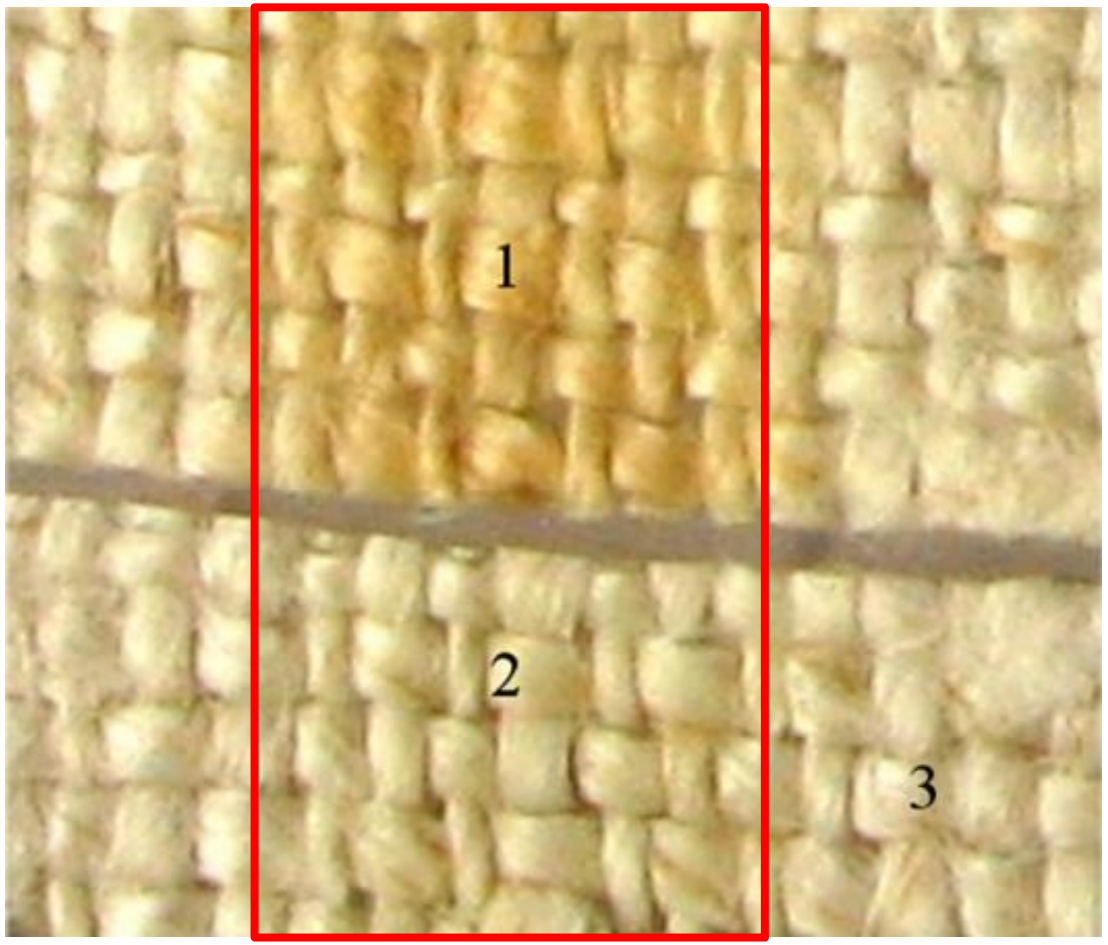
Half-tone effect by VUV irradiation



Microscope view of linen threads after VUV laser irradiation. Single colored fibers are visible next to uncolored fibers, like in the Shroud image (areal density coloration).

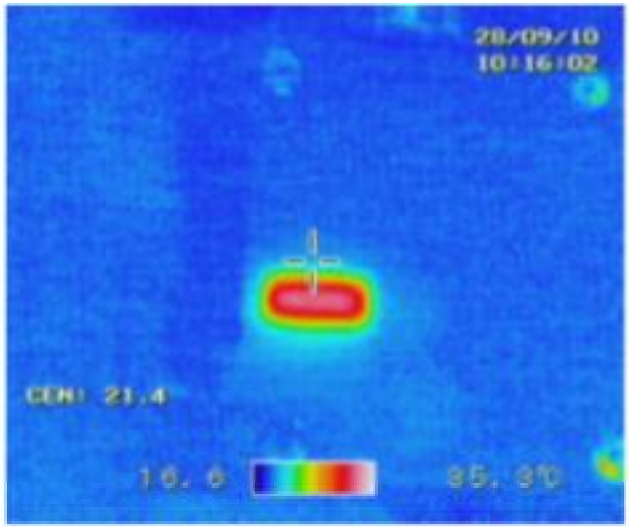
From *Applied Optics* ***51****, 8567 (2012)*

Latent images generated by VUV irradiations



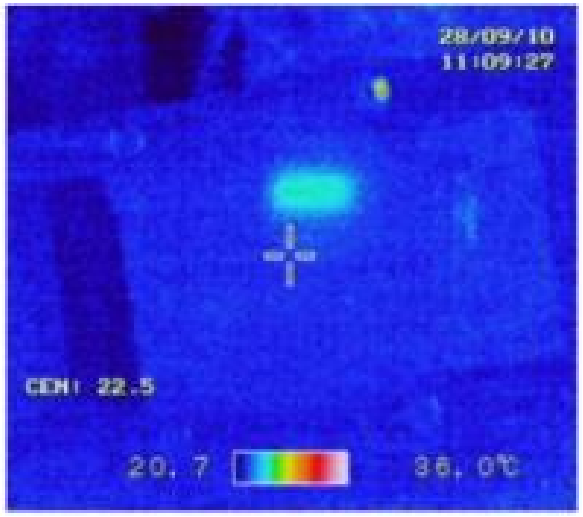
from J. Imag. Science Techn. ***54*** *040201(2010)*

Does UV generate a cold or a thermal coloration?



$\lambda = 308$ nm

T = 21 °C - 34 °C



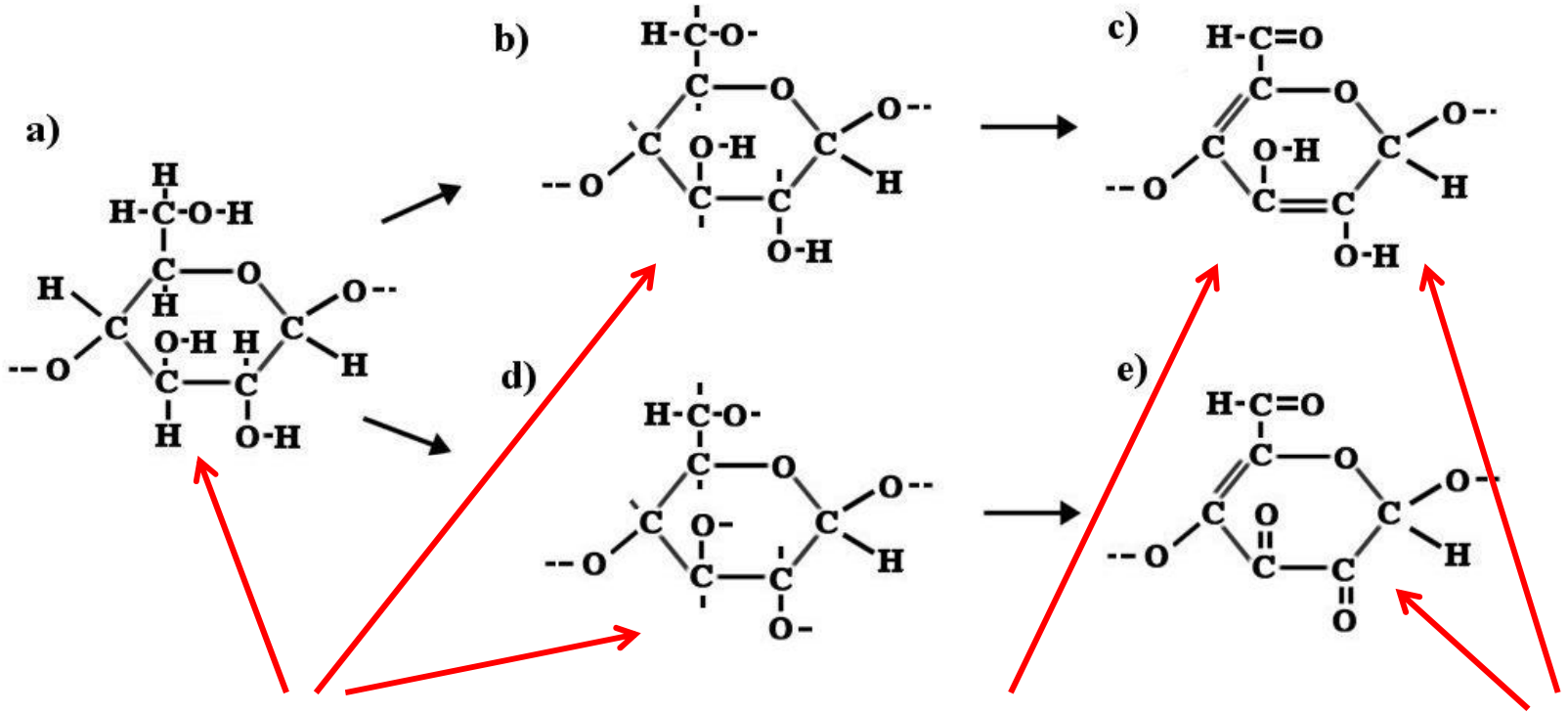
$\lambda = 193$ nm

T = 22 °C - 25 °C

Cellulose and UV radiation: studies of the '70s to understand the yellowing of old book pages

- ✓ Cellulose (chains of $C_6H_{10}O_5$) strongly absorbs photons with spectrum > 4 eV ($\lambda < 300$ nm, UV and VUV).
- ✓ UV radiation generates photolysis and photo-oxidation of cellulose.
- ✓ Chemical groups responsible for photolysis: aldehyde ($\lambda \approx 300$ nm) and ketonic carbonyl ($\lambda < 260$ nm).
- ✓ Macroscopic effects of UV absorption: cellulose bleaches or it becomes yellowed.

From cellulose to cromophore: the photochemistry of coloration



aldehyde -CHO

absorb λ < 320 nm (large bandwidth)

Alkene –C=C – and ketonic carbonyls – C=O

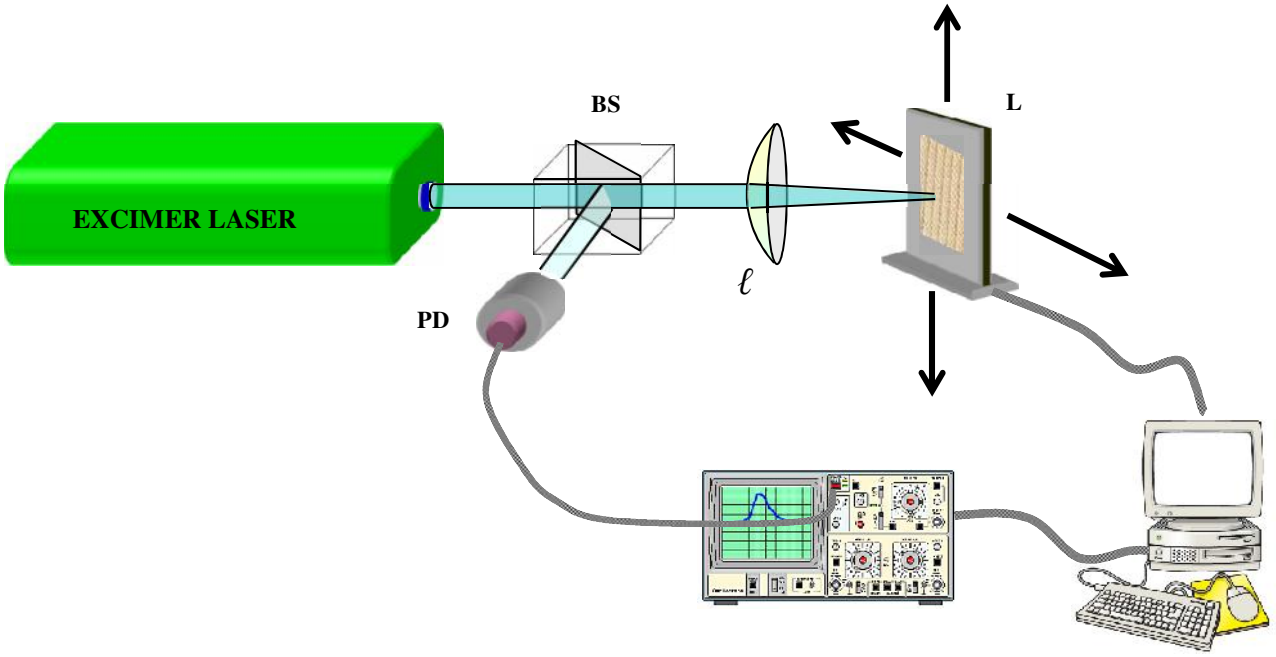
absorb λ << 260 nm

Aldehyde absorbs both 193nm and 308nm to generate cromophores. In addition, 193nm is absorbed by alkene and ketonic groups, thus delocalising groups and shifting absorption band to longer wavelengths, in the blue-green spectral region. This causes the yellow coloration.

J. Appl. Polymer Science ***16****, 2567-2576 (1972).* *Cellulose* ***1****, 205-214 (1994)*

Short movie

The excimer laser as a contactless brush



Shroud-like face using excimer laser as a brush

Shroud-like face imprinted by UV laser pulses.
It is invisible when viewed in the sunlight…
But…

Shroud-like face using excimer laser as a brush

Shroud-like face imprinted by UV laser pulses.
It is barely visible when viewed in the shadow…
But…

Shroud-like face using excimer laser as a brush

Shroud-like face imprinted by UV laser pulses.
It is well visible when making the negative of the image.
Even the single laser shots can be recognized.

Since 2013 it is exposed in the Museum of the Shroud in Turin

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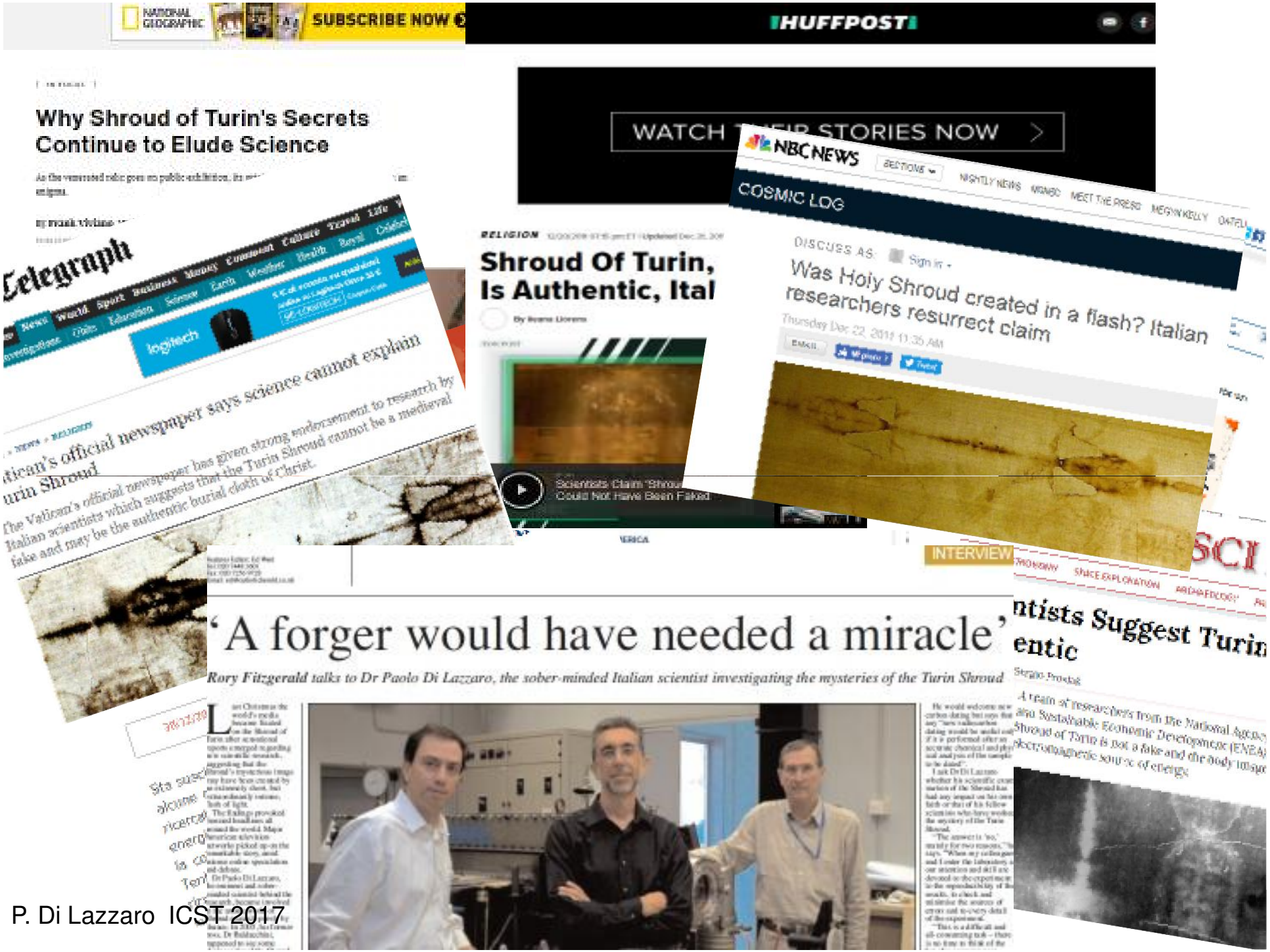

P. Di Lazzaro ICST 2017

Shortcircuit of media

Were statements from newspapers and web accurate?

- *"Italian team suggests the Shroud is authentic"* FALSE
- *"ENEA shows the body image on the Shroud was created by a flash"* FALSE
- *"Italian scientists say Science cannot explain the images on the Shroud"* TRUE
- *"ENEA demonstrates the Shroud is not a medieval fake"* FALSE

Then, there are scientifically correct data that are misunderstood by layman

Short movie

34 thousand billion watt is an impressive number, but…

- Back to basics: let us consider a fraction A/B. If B is very small, then A/B results in a very large number, independent of how much "big" is A.
- 17 joules energy/0.00000001 seconds results in 1.7 billion watt. It is called "**peak power**" which is different of the commonly used "**average power**".
- The above peak power was delivered to 1 cm^2 flax. Being the average man skin surface = 2 m^2 = 20,000 cm^2, we have 34 thousand billion watt necessary to complete the body figure of the Shroud.

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A scientific search for God?

"The scientific study of the Turin Shroud is like a microcosm of the scientific search for God.
It does more to inflame any debate than settle it...
And yet, the shroud is a remarkable artifact, one of the few religious relics to have a justifiably mythical status. ***It is simply not known how the ghostly image of a serene, bearded man was made***."

-- **Philip Ball, *Nature Online*, January 2005**

Partial list of image reproduction attempts

YEAR, MAIN AUTHOR	TECHNIQUE	MAIN DRAWBACK
1902 Vignon	Vaporographic	**Lack of resolution**
1940 Cordiglia, Romanese	Aloe+myrrh on cadavers	**Not superficial**
1978 Pesce Delfino	Heated bas relief	**Not superficial**
1983 Nickell	Iron oxide powder rubbing on bas relief	**Unlike at thread level**
1998 Allen	Ante litteram photograph	**Photosensitive chemicals unknown till XIX century**
2010 Garlaschelli	Dry ochre rubbing on bas relief	**Unlike at the fiber level**
2005-2013 Fanti	Corona discharge	**Conductive dummy only, image on the outer side**
2008-2014 Di Lazzaro	Ultrashort UV light pulses	**Life-size image is beyond today-technology**

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Summary of ENEA experimental results (1)

- ✓ We have shown how ultra-short UV and VUV radiation can reproduce many peculiar aspects of the microscopic complexity of the Turin Shroud images.
- ✓ UV radiation colors linen only in a **narrow range** of laser parameters: in particular, the single laser pulse must be **shorter than 50 billionths of a second**.
- ✓ The permanent linen coloration is a **threshold** effect, i.e. the color is obtained only if the total laser intensity/energy density exceed a certain value (thousands megawatts or few tenth of joules per square centimeter). Intensity values exceeding the "right" range of values burn the linen, while too small intensities do not change the linen color.
- ✓ We triggered a **photochemical** coloration process, because the thermal heating associated with UV and VUV radiation is within a few °C and therefore irrelevant for coloring purposes. This result fits the requirement of a coloring process at low temperatures according with STuRP analyses.

Summary of ENEA experimental results (2)

✓ The **hue of laser-induced coloration** depends on the radiation wavelength and on the number of pulses. Irradiations at 308 nm generate a dark yellow coloration, while the 193 nm photons generate a pale yellow color, similar to the Shroud image. In both cases, the color contrast increases with the number of laser pulses, allowing an **accurate control of the RGB** value by varying the total intensity.

✓ The different colors obtained by UV and VUV radiation is due to different chains of photochemical reactions. VUV radiation at 193 nm is absorbed by **ketone carbonyls**, inducing a **photolytic degradation** of the cellulose of the linen which promotes the formation of **double bonds C=C** and **C=O** which are the chromophores. **Chromophores** determine the fibers coloration.

✓ We observed irradiated fibers whose coloration was confined in the **primary cell wall**, which is comparable with the thinnest coloration depth observed in the fibers image of the Shroud.

Summary of ENEA experimental results (3)

✓After laser irradiations that do not produce a visible coloration of linen, a **latent coloration** appears either by natural ageing (more than one year later) or artificial ageing of linen. Latent coloration is interesting for the synergy of UV and de-hydration which trigger the coloration process, and for historians, attracted by the possibility that the Shroud images may have developed over time (years) from the moment the process of latent coloration acted.

✓ The **reduced fluorescence** induced by UV and VUV radiation is an additional feature of our coloration similar to the Shroud images. The induced fluorescence is also capable to selectively recognize the uniformity of coloration.

✓We locally obtained the gross shading structure that is determined by the ratio of yellow to uncolored fibers in a given area, the so called "**half-tone effect**" which is one of the most puzzling characteristic of the Shroud body images.

Indirect consequences of ENEA results

➢ Using a petrographic microscope, we have observed some **defects** induced by UV radiation in the linen fibers, similarly to very old fabrics. Thus, **UV generates an accelerated aging of the linen**.

➢ When considering the **highly unconventional hypothesis** of the Shroud collapsing into a **radiating body** proposed by Jackson, VUV light is compatible with both shading correlation with cloth-body distance and the absence of side images. This is because VUV photons are strongly absorbed by air.

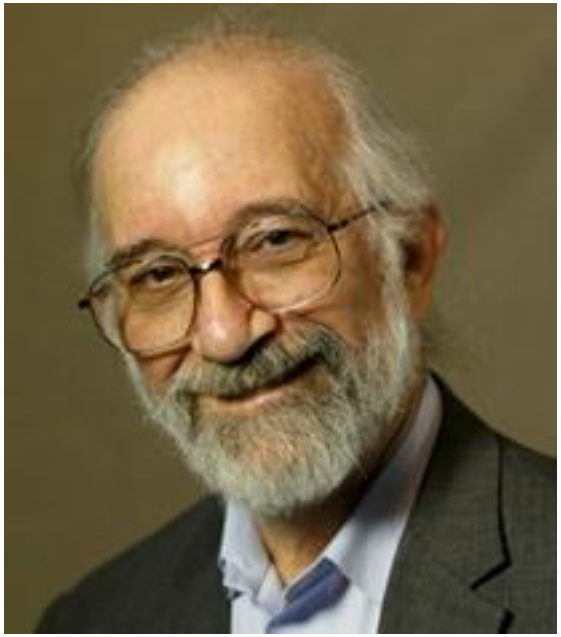
But But But…

When obtaining a Shroud-like coloration by VUV radiation, it does **not** mean the body image on the Shroud was generated by a flash of VUV light. From a scientific point of view, it means that **it is not impossible** that VUV radiation may have played a role in the image formation.

At last, what is the Shroud?

"A challenge to our intelligence", not only…

"We could tell you what it's not -not a painting, not a photograph, not a scorch, not a rubbing- but we know of no mechanism to this day that can make an image with the same chemical and physical properties as the image on the Shroud."



"People often ask me, **'Does this prove the resurrection?**'
The answer to faith isn't going to be on that piece of cloth, but more likely in the eyes and the hearts of those who look upon it."

Barrie Schwortz

Readings

- G. Baldacchini, P. Di Lazzaro, D. Murra, G. Fanti: "**Coloring linens with excimer lasers to simulate the body image of the Turin Shroud**" Applied Optics 47, 1278-1283 (2008)
- P. Di Lazzaro, D. Murra, A. Santoni, G. Fanti, E. Nichelatti, G. Baldacchini: "**Deep Ultraviolet radiation simulates the Turin Shroud image**" Journal of Imaging Science and Technology 54, 040302-(6) (2010).
- P. Di Lazzaro, D. Murra, E. Nichelatti, A. Santoni, G. Baldacchini: **Colorazione simil-sindonica di tessuti di lino tramite radiazione nel lontano ultravioletto: riassunto dei risultati ottenuti presso il Centro ENEA di Frascati negli anni 2005-2010** Rapporto ENEA RT/2011/14.
- P. Di Lazzaro, D. Murra, A. Santoni, E. Nichelatti, G. Baldacchini: "**Superficial and Shroud-like coloration of linen by short laser pulses in the vacuum ultraviolet** Applied Optics **51**, 8567-8578 (2012).
- P. Di Lazzaro, D. Murra: **Shroud like coloration of linen, conservation measures and perception of patterns onto the Shroud of Turin** SHS web of conference **15** 00005 (2015).
- P. Di Lazzaro, D. Murra: **A ray of light on the Shroud of Turin** Proceedings of the International Conference Fiat Lux, let there be light (E. Fazio, R. Pascual Eds.) (2016).