Color Analysis for the Digital Restoration of *Das Cabinet des Dr. Caligari*

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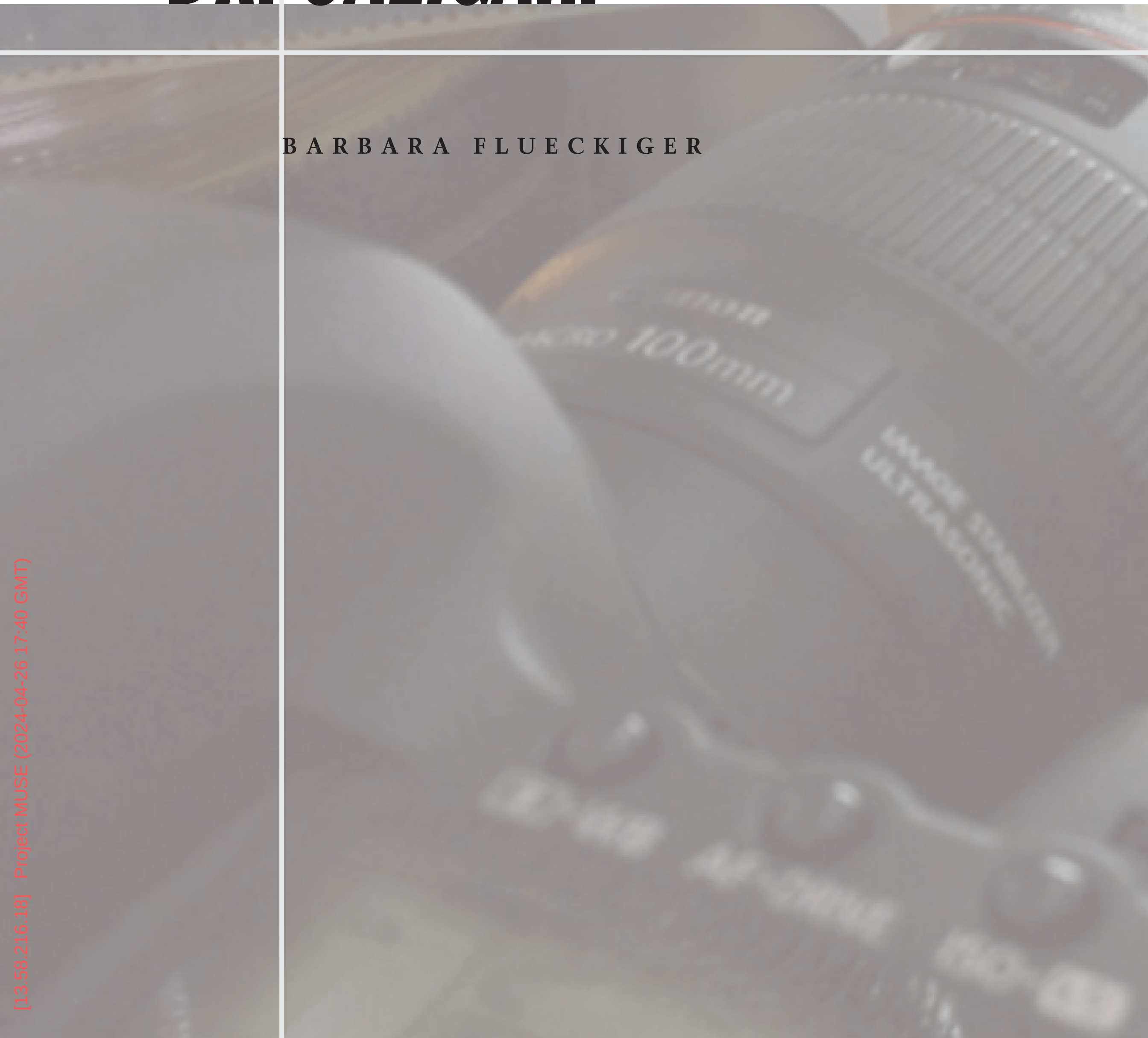
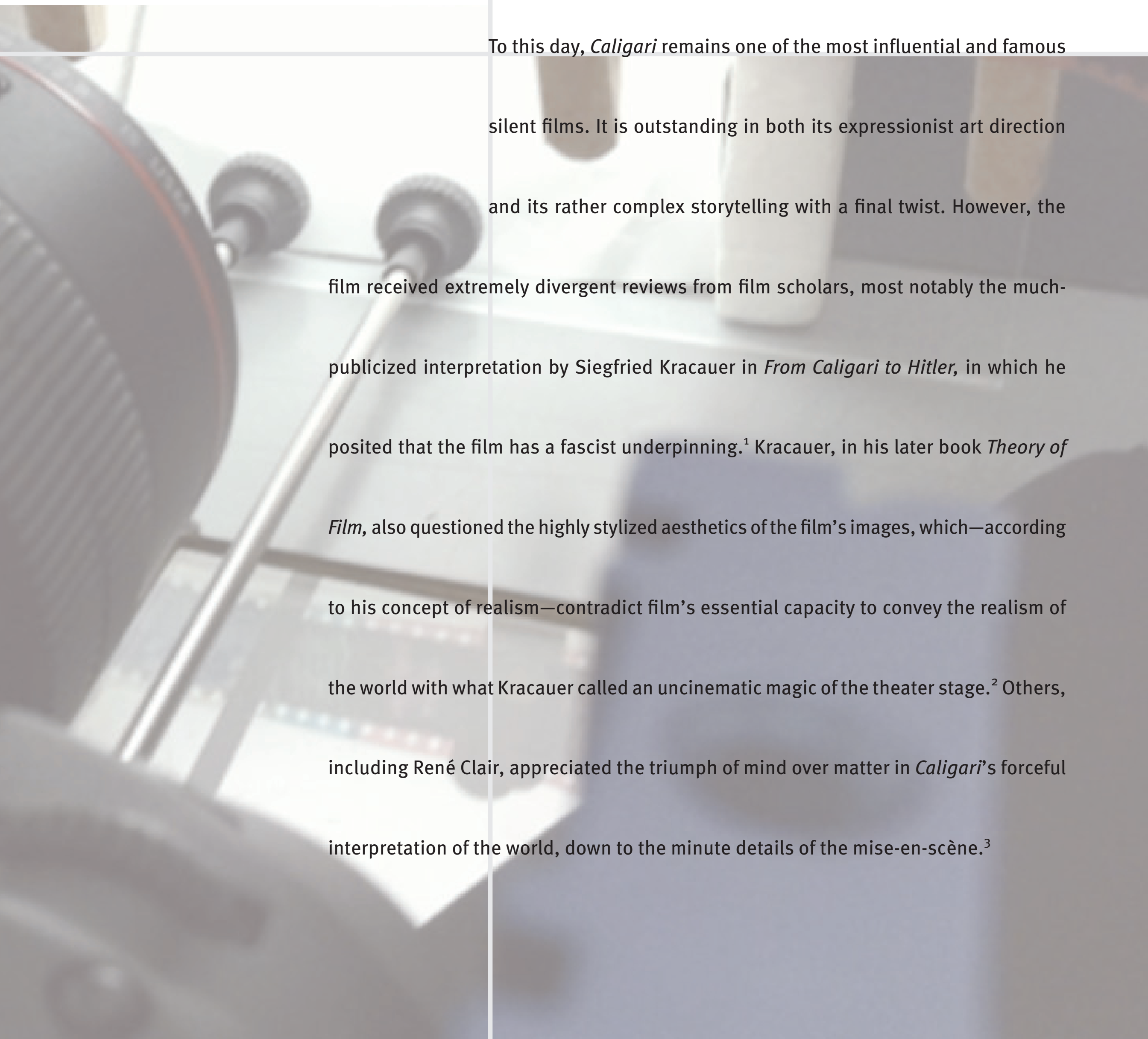


BARBARA FLUECKIGER



To this day, *Caligari* remains one of the most influential and famous silent films. It is outstanding in both its expressionist art direction and its rather complex storytelling with a final twist. However, the film received extremely divergent reviews from film scholars, most notably the much-publicized interpretation by Siegfried Kracauer in *From Caligari to Hitler,* in which he posited that the film has a fascist underpinning.[1] Kracauer, in his later book *Theory of Film,* also questioned the highly stylized aesthetics of the film's images, which—according to his concept of realism—contradict film's essential capacity to convey the realism of the world with what Kracauer called an uncinematic magic of the theater stage.[2] Others, including René Clair, appreciated the triumph of mind over matter in *Caligari*'s forceful interpretation of the world, down to the minute details of the mise-en-scène.[3]

Although the aesthetics of the film's mise-en-scène have been the topic of many scholarly texts and investigations, little to no attention has been paid to the colors applied to the film. This lack of research is a result of the history of the film's prints, with most of them having been transferred to black-and-white safety film. Because tinting and toning were applied to individual exhibition nitrate prints at the time, they were not transferred to later copies on safety film.[4] *Caligari*'s original colors have therefore been lost to generations of viewers. The 1984 restoration by the German Federal Film Archive notably contributed to bringing the tinted and toned images of *Caligari* back to the screen, based on a tinted and toned nitrate print from Montevideo and a copy with only tinting from the British Film Institute (BFI).[5] In 1995, the Cinémathèque Royale de Belgique undertook another color restoration based on the historical Belgian print, with the color schemes applied photochemically by the Desmet method, based on a second South American exhibition nitrate print.[6] The restored version was reduced to the four dominant hues. All the exterior and interior scenes with daylight or tungsten light were tinted in amber, while the night scenes, both exterior and interior, were tinted blue. A pale dusky pink indicated private scenes in the female protagonist's sitting room. Blue toning was combined with pale amber tinting for the exposition and for a later scene with the male protagonist, who narrates his unbelievable story.

In 2012, the Friedrich Wilhelm Murnau Foundation decided to make a completely new digital restoration under the supervision of head restorer and film scholar Anke Wilkening. The main motivation for this new restoration was the rediscovery of the original camera negative in the Federal Film Archive in Berlin, which for unknown reasons was never considered in earlier restorations.[7] A 4K scan from the negative resulted in a decisive difference in image quality, with regard to both details in the mid-tones and higher resolution. In addition, it was the first restoration to make extensive use of digital restoration tools and color grading.

The new digital restoration was also the first to consider the six currently known, differently tinted and toned historical prints from the 1920s. They are held by the following:

- Filmmuseum Düsseldorf, donated by a private collector from Montevideo
- Archivo Nacional de la Imagen-SODRE in Montevideo, now at the Cineteca di Bologna
- Cinémathèque Française
- BFI
- Cinémathèque Royale de Belgique
- Fondazione Cineteca Italiana, Milano, film fragment

In addition to the colored prints, the Friedrich Wilhelm Murnau Foundation used several other prints. One was a black-and-white 16mm print from the Deutsche Kinemathek, which was produced in 1935 for the collection of Gerhard Lamprecht and contained the original German intertitles. Another was the black-and-white camera negative from the Federal Film Archive, which included the original expressionistic German intertitles as flash titles (single frames that indicated the position of the titles and served as complete texts of the intertitles).[8] No contemporary colored nitrate print from Germany survives. Therefore the five copies mentioned in the preceding list were used to investigate and apply a color scheme. Despite having undergone an odyssey spanning almost one hundred years since the film was shot in 1919, the camera negative was in very good condition.[9] Decades ago, the negative was tarnished when it was chemically polished in an effort to reduce scratches. The first act is missing from the negative; individual frames are lost in many shots, and there are other lacunae.[10] To construct a new version, different parts from the various prints had to be scanned and combined with the scan from the negative.

All the prints and the negative were transported to L'Immagine Ritrovata in Bologna, a film laboratory specializing in film restoration. Anke Wilkening assigned the task of documenting the scientific analysis of *Caligari*'s colors and the colors themselves to the Swiss research project DIASTOR, in collaboration with Ulrich Ruedel from the BFI. Her objective was to document the colors not only for this current restoration but also as a color reference for future restorations of this film. DIASTOR is an applied interdisciplinary project developed and managed by the author of this study.[11] Based at the University of Zurich, the project combines film-historical knowledge and restoration ethics with advanced research in IT and the technological expertise of Swiss service providers and engineering companies. The goal is to offer custom-tailored solutions that bridge the gap between analog film history and digital technology. It is one of DIASTOR's main goals to develop nondestructive, scalable solutions for a variety of materials in different conditions and for diverse color processes, including a special focus on improving the scanning and rendition of applied colors such as tinting, toning, hand coloring, and stencil colors. DIASTOR has developed a variety of interdisciplinary approaches to test the *Caligari* materials but also to investigate a wide range of methods for their analysis and documentation.

OBJECTIVE OF THE COLOR ANALYSIS

There were several research topics related to the color analysis of *Caligari.* First of all, Wilkening proposed comprehensively documenting the different tinted and toned nitrate prints that were in Bologna for this restoration. An exhaustive analysis of the films had previously been made by the Friedrich Wilhelm Murnau Foundation in Wiesbaden, with regard to their completeness, the condition of the material, and their color schemes. This was continued by L'Immagine Ritrovata to devise a workflow for the digitization of the material. Wilkening and restorer Paola Ferrari wrote a detailed report on the *Caligari* negative and positives as well as on the problems present in the nitrate films. The goal was to reconstruct the full text and fill the lacunae in the negative based on scans from the copies. However, this report did not provide a reliable color reference. Photographs for the report were shot using amateur cameras and did not render the colors as they appeared on visual inspection. One research topic therefore focused on the task of devising a method for capturing the colors of the nitrate prints.

Further work centered on revealing reliable information about the genealogy and relationships of the differently colored prints. Because no contemporary German print survived, the restorers had to collect as much valid information as possible about historical color schemes of prints in Europe, so as to provide a basis for the color scheme to be applied to the scan of the black-and-white negative during color grading. The decision to scan from the negative was made for several reasons. First, the negative was decidedly superior in resolution and tonal range compared to any of the positives. It was also in rather good condition, although the thorough repair of perforations and splices was required.[12] Finally, the negative was surprisingly complete, apart from the aforementioned omissions and missing first act. As noted earlier, two of the surviving prints—and the two earliest ones—stemmed from the South American market. They were deeply saturated with tinted and toned colors (Plate 3).

As Nicola Mazzanti has notably argued, South American prints were often considerably different from European ones.[13] In the group of films he researched—Italian art films from the 1910s—he observed a tendency toward simpler color schemes and brighter, more saturated colors. The assumption that distributors had their prints colored according to specific culturally determined tastes of the local audience shed some doubts on the appropriateness of South American prints as resources for the reconstruction of the color schemes in the restoration by the Murnau Foundation. The most completely colored positive is the one from the Cinémathèque Française. Its color scheme shows many similarities with the South American copies, but it is obviously from a later date. The notable print-through details from splices and perforations, which are not visible in the earlier copies, are due to a change in processing technology. This technology used an intermediate negative in such a way that splices occurred only where the tinting and toning changed (Plate 4).[14]

Furthermore, the technical and aesthetic quality differs considerably from the

South American copies, because the French print is higher in contrast and contains less detail in both highlights and dark areas. The highlights especially provide little information. The French nitrate print contains an inserted clip which is toned in a vivid blue marine, as opposed to the surrounding dark blue toning in combination with yellow to orange tinting. The British version from the BFI and the Belgian version from the Cinémathèque Royale are simplified in their color schemes and have no tinting–toning combinations. Judging from the similar imprints of splices, they were produced later than the South American versions. The identification of the dyes was essential in reconstructing the relationship between the different prints and in revealing more information about the possible color scheme of the German prints.

METHODS

A number of methods were applied to investigate the color compounds of the tones and dyes of the tint, their chemical compositions, and their physical properties. Apart from answering the immediate questions as outlined earlier, our goal was to test different research methods from a variety of fields to understand the significance of their possible outcomes and their range of applications. It was an absolute restriction, however, that the method should be nondestructive to prevent damage to the nitrate prints. The second big practical obstacle originated from the film reels themselves. Obviously, the film base was highly flammable cellulose nitrate, but these copies were also very precious, rare film elements. As a consequence, it was out of the question to transport any reel to Zurich, where a variety of labs at the Swiss Federal Institute of Technology—a DIASTOR project partner—could have been utilized. Therefore the tests had to rely on single frames from the French copy that had been glued to the covers of the film cans.

Photographic Documentation of Colors, Edge Information, and Splices

Before starting the scientific analysis of the materials, the immediate task was to document the visual appearance of the various tints and tones, in combination with edge information and with a special focus on the splices. A custom-tailored camera setup (Figure 1) had been constructed for an earlier research project on film colors to capture photographs of films for the “Timeline of Historical Film Colors.” Portable and modular, it consists of a Canon EOS 5D Mark II DSLR camera with a 100mm macro lens. The quality of the lens is crucial to avoid chromatic aberration and to minimize distortion. The camera is set on a Novoflex macro slide with a right angle bracket. In front of the slide,

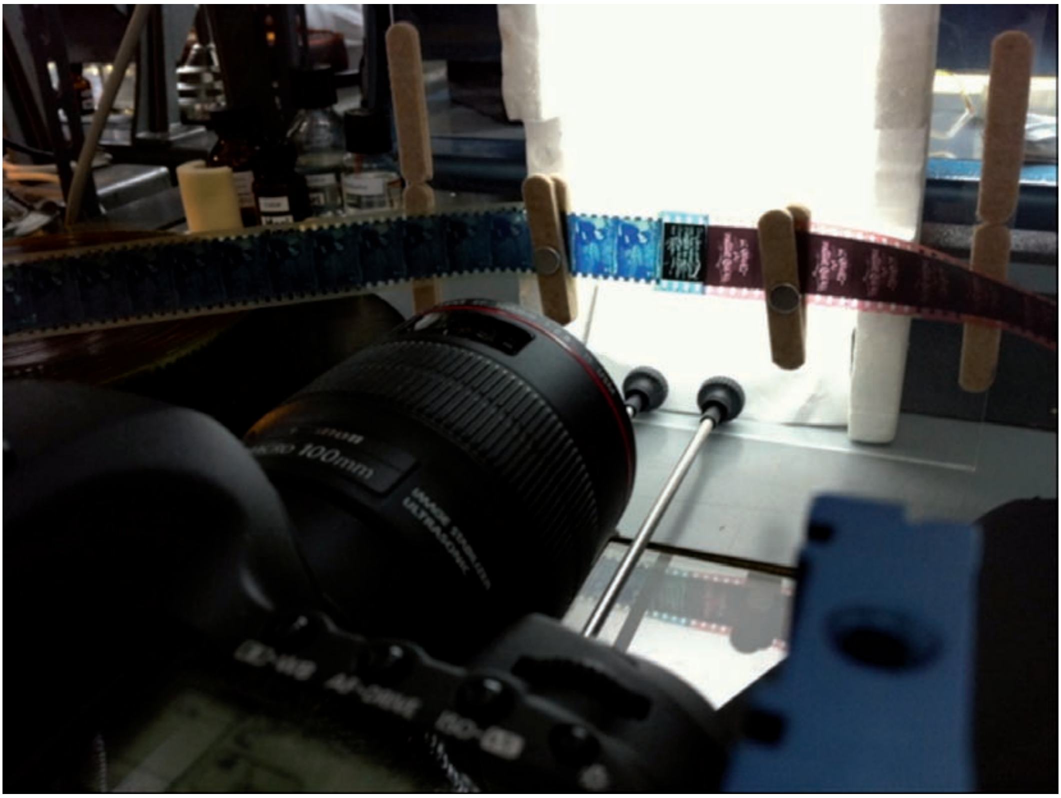


Figure 1. Modular camera setup by Barbara Flueckiger. Photography by Barbara Flueckiger, "Timeline of Historical Film Colors" (http://zauberklang.ch/filmcolors), Research Project DIASTOR (http://www.diastor.ch/).

a piece of Plexiglas is attached on a planar angle parallel to the camera. Felt strips with magnets gently attach the filmstrip to the Plexiglas, avoiding any damage. Various light sources are available to backlight the filmstrip: a diffuse LED light source with adjustable color temperature (from 3,200 K tungsten to 5,600 K daylight, a light panel with a color temperature of 5,000 K, or a spot light source with 5,600 K).

An IT8 backlight target serves to calibrate the camera system by providing a color profile. The whole system is remote-controlled by EOS utility software on a computer, which allows the adjustment of all parameters: exposure, focus, color temperature, and aperture. Furthermore, the focus is controlled automatically but is then adjusted to the selected plane manually using the zoom-in function. Tests have shown that an aperture of *f*/11 provides the best compromise. This enables higher depth of field than a larger aperture, yet avoids aberration problems that occur at smaller apertures. Exposure is usually set to a fixed time for a whole film and generally varies between 1/8 and 1/4 seconds, depending on the film stock. In the case of very high dynamic range, a bracket of two or more shots is taken, allowing all details in both the dark and light image areas

Figure 2. (a) Photographic documentation. (b) Magnification. Photography by Barbara Flueckiger, "Timeline of Historical Film Colors" (http://zauberklang.ch/filmcolors), Research Project DIASTOR (http://www.diastor.ch/), © Friedrich Wilhelm Murnau Foundation.

to be fully recorded. Exposure and dynamic range are set using a remote live-view function and based on a histogram displayed in the software.

This camera setup produces images that are very close to the visual impression in daylight. In this respect, it is superior to a flatbed scanner, and the camera's resolution of eighteen megapixels is very high. It therefore accurately captures the frame's grain texture (graininess) and all the details in the nonimage parts, such as frame lines, edge marks, and details of the splices (Figure 2). Even the tiny lighter spots, which might have resulted from microorganisms or initial problems of the applied colors in the French copy, became visible.

During two two-day sessions, all the colors in all the five prints were captured. With the help of Ferrari, who was responsible for the analog restoration of the film elements, and based on the documentation provided by Wilkening, the author went through all the reels to spot the colors, even including the smaller variations between two different green and blue tints, respectively.[15] Although the color schemes of the two South American prints were identical in principle, there were considerable variations in density and hue. The Düsseldorf copy was even denser than the very dense Bologna copy. In cases where the dark blue toning was combined with the orange tinting, the blue areas were so dark that they tended to be perceived as almost black on visual inspection. Despite the calibrated camera system, even slight variations in exposure or illumination changed the colors significantly, and an unwanted shift to green hues emerged in those lighter parts where blue tinting and toning overlapped in mid-level areas. The method requires the constant comparison of the photographic results with visual inspection and means that the camera system must be fine-tuned to deliver optimal results without the necessity of later adjustments, when the reference material would be missing. An additional series requested by Wilkening focused on specific splices where different colors were adjacent to each other for more information about the applied color schemes.

During color grading in the final application of the colors to the black-and-white scan of the negative, the photographs served as a major reference, in combination with photochemical color samples and the comparison of the nitrate print on the bench.[16] The photos are therefore not only a documentation of the array of all the applied color schemes and the finely adjusted rendition of the colored film materials but also a useful guide for translating the colors to the final digital master.

Tests with Various Types of Illumination

As the author has elaborated elsewhere,[17] every image of a film—be it a scan or a photograph—is only one specific reading under certain conditions. It is never able to capture the film's material properties in its entirety. It is therefore crucial to document the principles—epistemological and physical—of every capturing device. Every picture and every scan is the result of a specific interaction between light, matter, the image sensor, and its postprocessing chain. As a consequence, one of the basic steps in investigating the color appearance of the tinted and toned nitrate prints included tests with various types of illumination. Our investigation was indebted to the insights and research of Giorgio Trumpy.[18] As he explains, in addition to spectral distribution and color temperature, the direction of the light rays is crucial for color and contrast rendition. Although all projectors produce directed light rays—so-called collimated light—as a result of their lens configuration, most capturing devices, including scanners, operate with diffuse light sources. Collimation of light converges the light rays for best results in illumination, sharpness, and resolution on the distant projection screen in a movie theater. To reproduce this configuration for the capturing of photographs of film, a converging lens—the so-called condenser—has to be placed between a point light source and the capturing device in such a way that the focal point of the light rays coincides with the focal point of the lens.[19] The filmstrip is placed between the condenser and the lens of the camera in such a way as to produce a completely sharp image. This optical configuration produces the so-called Callier effect, which enhances small-scale contrast and, therefore, the perceived sharpness of the image.[20] While the scattered light that emanates from diffuse light sources produces the opposite effect, the attenuation of small-scale contrast as a result of light rays overlapping each other, collimated light has an unwanted side effect, namely, the utterly sharp reproduction of scratches and dust and other blemishes present on the filmstrip (Plate 5).

With regard to color, however, the Callier effect has results that are surprising and only partially understood at this time. Specialists involved in color film restoration are aware of the significant difference between the appearance of the film's color on the bench and that projected onto the screen. To investigate this effect, the author retrofitted a historical slide projector from the 1920s so that she could place the single film images in a wooden frame and project them onto a screen. This projector allowed us to use different illumination sources, such as an LED daylight spot or a tungsten light. The results showed that the shift in color appearance is not only very noticeable but also complex and somewhat paradoxical. In general, as expected, the contrast was enhanced so that the tinted image parts appeared brighter while the toned or darker parts shifted to black (Figure 3).

Surprisingly, the brighter tinted areas not only shifted to a higher level of brightness but also appeared different in hue and saturation. Yellow and orange tinting became more saturated and its hue shifted toward the yellow primary, especially visible with light orange tinting on the tinted–toned combination. The rose tinting in the French version, however, partly lost its color and appeared as a dusky pink.

As limited as these analyses and tests were, they pointed to a larger and still unresolved problem. All film scanners operate with a diffuse light source. As DIASTOR's ongoing scanner tests show, the lighting and sensor setups of most scanners are not designed to capture historical film prints as they appear on the screen.[21] One of the principal obstacles to using a collimated light source in the scanning process stems from the fact that such an optical configuration would require a larger setup. The smaller the setup is, the more it produces a pronounced hot spot. To achieve even illumination, the distance between the condenser and the image plane has to be long enough to result in an even bright field.

Physicochemical Measurements of Dyes and Color Compounds

We applied several methods of physicochemical measurement to identify the spectral characteristics of the dyes in the tinted stock and of the pigments in the blue toning. As mentioned earlier, two varieties of blue toning were present among the color samples:

Figure 3. (a) Diffuse illumination, daylight. (b) Collimated illumination, daylight. (c) Collimated illumination, tungsten. Photography by Barbara Flueckiger, "Timeline of Historical Film Colors" (http://zauberklang.ch/filmcolors), Research Project DIASTOR (http://www.diastor.ch/), © Friedrich Wilhelm Murnau Foundation.

a dark blue in the case of the orange tinting–blue toning combination and a lighter blue marine in the case of the inserted clip in the French print. Therefore we took additional measurements to identify the compounds present in the blue toning and to answer the question of whether the two varieties were related to each other by both being blue metal toning with Prussian blue, or whether the lighter blue was a mordant toning.[22] A visual comparison of the blue tones with samples from various tinting and toning manuals allowed for both possibilities. Manuals consulted included *Le Film vierge Pathé: Manuel de développement et de tirage, Agfa Kine-Handbuch,* and various editions of the Eastman Kodak Company's *Tinting and Toning of Eastman Positive Motion Picture Film*.[23] Prussian blue resulted in a variety of very different hues and shades. Bob Mabberley, Paul Read, and Sonja Snoek attribute this effect to different chemical procedures: "The various blue iron tones vary with the formula and whether the film was 'fixed' out."[24] Furthermore, these colors can darken with age. A comparison of different samples from a variety of copies of the preceding manuals shows a wide spectrum of color appearance as a result of applying various toning recipes.

Spectrophotometry

Initial tentative tests with a spectral camera proved that the spectral resolution for analysis should be much finer than the eight spectral bands available with this apparatus over the range of visible light. For more accurate spectral measurements, we applied two methods: one series of measurements with the X-Rite Color i5 Benchtop Spectrophotometer at X-Rite/Pantone Europe GmbH in Regensdorf, Switzerland, and a second series with a microspectrometer done by Michael Göllner with Thomas Pfohl at the University of Basel's Institute of Physical Chemistry.

The X-Rite Color i5 has a range from 360 to 750 nanometers in 10-nanometer intervals (X-Rite specifications). It applies pulsed xenon light calibrated to D65 daylight to the transmittance–absorbance measurement. Probes have to be placed in a metal clip with selective apertures of a minimum of six millimeters. Two problems were noted in the measurement process. First, the attachment of the probe needs to be adjusted for filmstrips. We were only able to attach the film frames, because they were cut out of the film. Furthermore, the clip itself was not very gentle on the material. Second, the minimal aperture of six millimeters was quite large in relation to the overall size of the film frame. It therefore proved to be rather difficult to find pure, untarnished areas of only one color to deliver a proper result. X-Rite employees Marco Hilhorst and Jochen Mohr carried out the measurements in our presence. Mohr also analyzed the results. Working from an

Excel table of the absorbance results, we were then able to compare the transmittance with documented information about spectral properties of dyes and pigments, such as the Sigma-Aldrich *Handbook of Stains, Dyes, and Indicators.*[25] However, this comparison required the normalization of the gathered data to produce similar scales. Plate 6 shows that the light blue toning in the inserted clip has an absorbance spectrum that is strikingly similar to that of Prussian blue (ferric ferrocyanide, $Fe_7(CN)_{18}$). In contrast, the darker blue toning in the tinting–toning combination showed some deviations, with several individual peaks in the range between 600 and 750 nanometers. At a later stage, these peaks were interpreted as measurement artifacts, most probably a result of refraction caused by scratches on the film's surface.

To avoid the problem of the rather large aperture of the spectrophotometer, we turned to microspectrometry in collaboration with Professor Pfohl's lab at the Department of Chemistry of the University of Basel. This apparatus consists of an LED light source that is directed via a glass fiber to a small metal bench. Because the measured patches are very small in microspectrometry, it is crucial that the position of this bench can be remotely controlled in micrometer steps. It proved to be very difficult to position the film frames on the bench. The spectra had to be background-corrected by measuring the clear nitrate support (or the tinted areas, respectively) to deliver results for the blue toning. In discussion with Pfohl's group, Göllner came to the conclusion that many measurements are required in different areas to gain stable results. In microspectrometry, each individual result is deeply influenced by the concentration of the pigments or dyes at the locus of measurement. Therefore the measurements are subjected to a high degree of randomness caused by the uneven distribution of pigments in the emulsion.

Raman Microscopy

A similar problem occurred using Raman spectrometry and microscopy. Raman spectrometry is capable of identifying chemical structures based on Raman scattering, the inelastic scattering of photons. A monochromatic laser beam is directed at the sample and is, in parts, absorbed, reflected, or scattered. It thereby produces characteristic patterns in relation to the Raman scattering of the molecules present in the sample.[26] It has been applied to the identification of chemical compounds in artworks before, especially for the study of pigments in frescos, because frescos allow for the extraction of small samples without causing visible damage to the artwork. However, as Nobel laureate Richard R. Ernst, emeritus of the Federal Institute of Technology in Switzerland, notes, very few studies reported using Raman microscopy for the analysis of paintings on fabric or paper, because of the necessity for taking samples of the applied colors, which

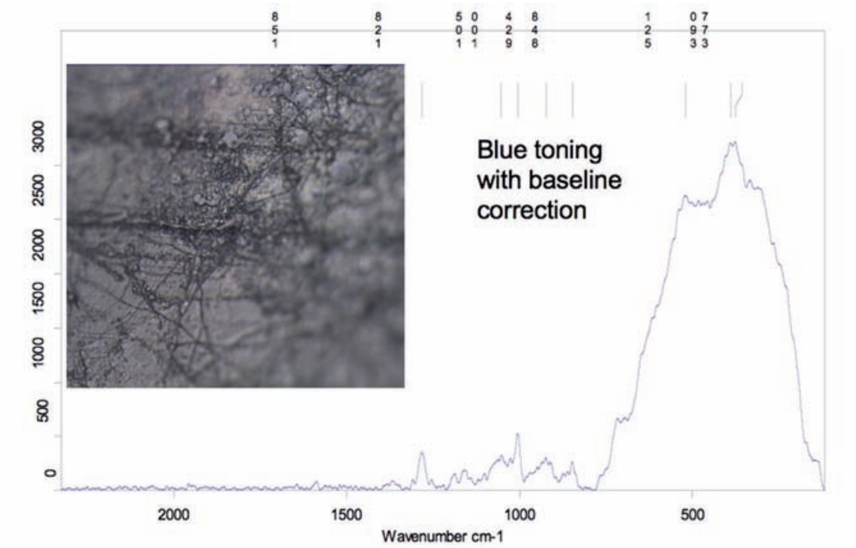


Figure 4. Raman microscopy by Richard R. Ernst.

damages the structure of the paintings.[27] As a reaction to this limitation, Ernst has developed a nondestructive system that allows him to successfully analyze pigments in his studies of large Central Asian *thangka* paintings.[28]

The same considerations apply in the case of very rare historical films such as *Caligari*. Therefore Raman spectroscopy is, in principle, a very valuable method for analyzing chemical structures present in film emulsions, such as chemically applied colors (in tinting or metallic toning) or dyes (in tinting, mordant toning, or later processes such as Technicolor or chromogenic film). As Ernst's study of the *Caligari* frames has shown (Figure 4), the method requires the analysis of a wide range of film materials to deliver stable and unambiguous results. Without this comparison, it would be impossible to exclude the influence of molecules other than those associated with the colors, and the results would remain unclear. Ulrich Ruedel compared this problem to the task of measuring the weight of a ship's captain by weighing the ship once with and once without the captain. As in microspectroscopy, it would be preferable to isolate the colors to be analyzed, but that is impossible without destroying the sample of film material.

Although Raman microscopy did not provide immediately useful results for our study, it proved to be a very accurate and rich method for the nondestructive investigation of film colors. Therefore we need a research project where this method can be systematically applied to analyzing colored film in connection with reliable documentation about the chemicals applied, as in the Pathé, Eastman, or Agfa manuals mentioned earlier. DIASTOR is currently investigating this topic for a future research project.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry

The next method for the analysis of the *Caligari* sample was semidestructive laser ablation inductively coupled plasma mass spectrometry. We collaborated with the Laboratory of Inorganic Chemistry of Detlef Günther, Department of Chemistry and Applied Biosciences at the Federal Institute of Technology, one of DIASTOR's project partners. They describe the method:

> In laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) the aerosol analyzed by ICPMS is generated by evaporating (ablating) a solid sample by means of a high-energy pulsed laser beam, which is focused on the sample surface. The ability to concentrate laser energy into an area as small as 4µm in diameter for current equipment enables spatially resolved elemental analysis of major, minor, and trace elements and isotope ratio measurements in almost any solid material.[29]

Laser beams are shot at very tiny spots in the material. The tricky part, particularly with regard to nitrate film, results from the procedure's extremely high temperature, namely, 10,000°C. Therefore we decided to test this method only on a separate tinted nitrate stock fragment belonging to DIASTOR team member David Pfluger. Laser ablation is usually used to identify solid materials, such as gemstones. Surprisingly, though, the laser beam did not ignite the nitrate; it perforated only the planned series of very small samples (Figure 5). Regardless of this minimally destructive result, we decided to abandon this path after a discussion with Wilkening because we deemed it too risky. As Bodo Hattendorf and Günther explained, there is a portable unit able to extract tiny particles of material for later analysis at the Laboratory of Inorganic Chemistry.[30] Therefore it would be possible to apply the method on-site in a film lab, although the method is restricted to the analysis of inorganic elements.[31]

X-Ray Fluorescence

At the same time, we utilized X-ray fluorescence in collaboration with Beat Aeschlimann at the Laboratory of Inorganic Chemistry. In the past, X-ray fluorescence has provided very good results for the analysis of film, and it is a widespread and well-established method used in art restoration.[32] High-energy X-ray beams produced by a rhodium tube are directed at the sample at a certain angle. The resulting dispersive X-ray fluorescence

Figure 5. Microscopic holes shot out by the laser ablation inductively coupled plasma mass spectrometry. Rose-tinted film fragment owned by DIASTOR team member David Pfluger, measurement by Beat Aeschlimann, ETH Zurich, Laboratory of Inorganic Chemistry, Günther group.

spectrum is processed and analyzed based on a database of typical patterns of Kα emission lines.[33]

This lab's specific technical setup requires that individual frames be available because the X-rays have to travel through a vacuum, but mobile equipment is available that works without a vacuum. A further requirement concerned the position of the sample, which must be aligned completely horizontally to provide even results. Therefore we arranged the individual samples in metal frames. A video camera in the apparatus displays the position of the sample, with a slight offset. The measurements deliver two different kinds of results. First, one receives a spectrogram that identifies various chemical elements present in the sample, based on a database implemented in the data-processing software on the computer. These peaks indicated the significant presence of iron and potassium in both samples. Günther observes, "Fluorescence is element-specific and can be mapped by a spatial resolution of the capillary optics."[34] On the basis of these results, Aeschlimann did a line scan to measure the spatial distribution of the two elements:

> Micro-X-ray fluorescence spectrometry (Egale [*sic*] II, Röntgenanalytik GmbH, Taunusstein, Germany) was used to generate element mappings. Therefore,

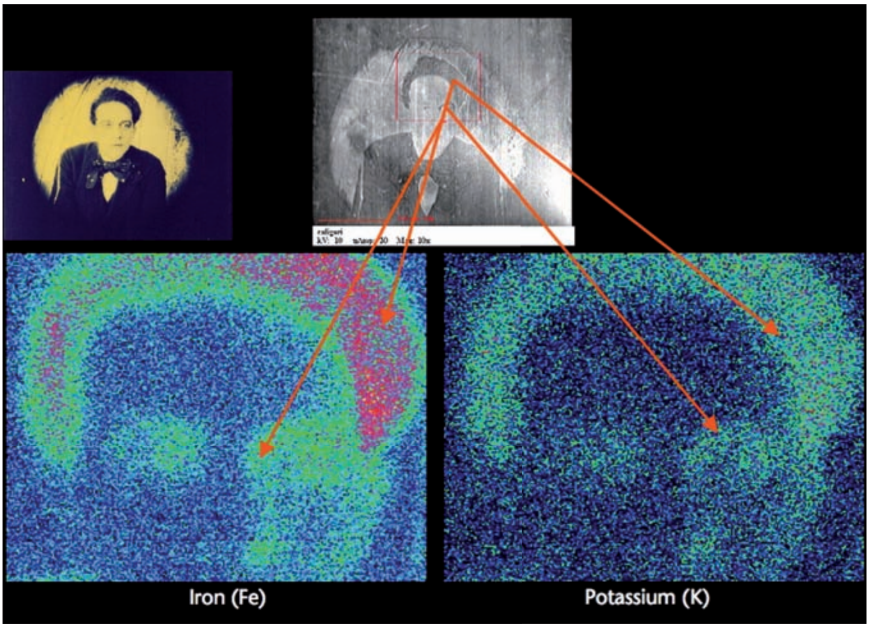


Figure 6. X-ray fluorescence line scans indicate the presence of iron and potassium in the blue-marine toning. Measurements by Beat Aeschlimann, ETH Zurich, Laboratory of Inorganic Chemistry, Günther group.

> a 50-μm spot size of a rhodium X-ray tube (25 kV, 600 μA) was focused on the sample surface and scanned a selected area (5.72 × 4.71 mm, 256 × 200 points). The intensity of the fluorescence of selected elements (Fe, K) was measured with a spatial resolution of x = 22 μm, y = 24 μm. The intensity images were converted into false colour images and provide qualitative information only.[35]

By means of transfer to a color-coded indication of concentrations in relation to their loci, Aeschlimann thus produced maps that displayed color-coded images of the iron and the potassium concentrations, respectively (Figure 6). These images were the final proof that both the vibrant blue toning and the dark blue toning consisted of the same color pigments, namely, Prussian blue.

DISCUSSION OF THE METHODS

Although it may be quite easy—as Paul Read explains—for the trained eye to identify dyes and pigments on visual inspection, there is still room for doubt in individual cases, especially when the appearance has been altered due to aging processes that lead to fading, blackening, or a significant shift of the hue.[36] To understand the chemical and physical properties of individual colors, it is necessary to investigate them thoroughly. As shown by the various methods applied, the biggest obstacle for the scientific analysis of colors stems from the requirement to use a nondestructive method. Mabberley, Read, and Snoek describe a chemical analysis that requires the destruction of a small piece of film:

> About 1cm square of film is needed as a minimum. The film is soaked in water to soften the gelatin, then the emulsion is removed with 3N NaOH solution, just enough to cover, taking about 2 hours. Heating is not usually required. The resulting solution or dispersion, after removing the film base, is then filtered or decanted and the solution treated (very carefully) with an equal volume of 3N nitric acid. The resulting acid solution is then subjected to the usual Group analyses. . . . In the case of iron tone blue the metal identifies as iron alone. Many other colour tones key out as iron (from the ferro-cyanide ion used as the bleach), and one other metal.[37]

It has to be noted, however, that only inorganic compounds can be analyzed using this method; organic dyes such as the aniline dyes applied in tinting are excluded but may be analyzed by other methods.[38]

Normally it is inadvisable to cut pieces out of historical film elements, even if they are exhibition positives. Usually very few of them have survived, and the case of *Caligari* has shown that such historical prints can become very precious. Therefore we need more studies using nondestructive methods, such as the ones presented in this article. From a long-term perspective, Raman spectroscopy in combination with X-ray fluorescence and spectrophotography might provide the most reliable results. As the example of Raman spectroscopy has shown, we need systematic exploration of this method to build up a database of reference values for testing tinted or toned film stock.

CONCLUSION AND OUTLOOK

Since its premiere at the Berlinale Festival in February 2014, the newly restored digital version of the film has sparked vivid interest in the archival community and general audiences. However, it has also met with some criticism, such as that expressed by Jan-Christopher Horak: “As I wrote on my Facebook page, I caused a mini scandal at the discussion, because I dared to ask why the Germans spend millions of Euros repeatedly restoring the five great German classics, while literally hundreds of German nitrate prints from the silent era rot in the archives in Germany and abroad."[39] This objection is certainly justified and points to a severe lack of political awareness in Germany and other countries worldwide. One could observe, though, that the tools of analysis and restoration techniques used for *Caligari* could be applied to any project.

The new restoration of this classic shows that digital means allow for the much more complex integration of a variety of source elements into the final version. This is especially true with regard to colors. One of the main obstacles for the restoration of early applied colors remains the interaction of the silver image with the tints and tones. Tinted and toned images are not merely black-and-white images enhanced by colors. They show a vivid and detailed palette of mid-range tones where more subtle interplays between chemical dyes and color compounds, the nitrate base, and the emulsion with the projection light occur. Therefore the color analysis executed by DIASTOR was a necessary step for the scientific underpinning of digitally applied colors to black-and-white scans. Such uncolored scans are the result not only of a workflow that starts with the most detailed film element, the camera negative, but also of the fact that many available scanners are not able to capture early film colors close to their visual appearance. The photographs taken to document the film colors provided a much more accurate color reference, while the physicochemical analyses enabled a close study of the colors' properties and the relationship between the different colors applied to the various nitrate film prints. At the 2014 FIAF Summer School, Grover Crisp from Sony Pictures Entertainment suggested that the original scans should be done in the highest resolution possible to provide future editions with new digital tools. As the example of *Caligari* and the DIASTOR scanner tests has shown, however, some film elements, especially the negatives scanned, do not contain the final colors, and most of the currently available scanners are not capable of capturing the spectra of early film colors. Therefore the careful documentation and analysis of colors as executed by DIASTOR for the *Caligari* restoration is even more valuable for future application. We will probably never be able to simulate the appearance of historical film colors in full detail. Refinements of the methods developed so far, however, will contribute toward approximating them with a higher degree of accuracy.

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NOTES

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8. Ibid.
9. See detailed analysis of the camera negative's history in ibid.
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13. Nicola Mazzanti, "Colours, Audiences, and (Dis)continuity in the 'Cinema of the Second Period,'" *Film History* 21, no. 1 (2009): 71.
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