PRACTICAL WORK ON COLOR EMULSIONS USING FILTERED Duplicates.
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1. INTRODUCTION

Color emulsions are widely used by Observatories in their public relations. For scientific research purposes, color films have scarcely been used. Astronomers prefer to use black and white photographic plates or film because color films are less efficient as well as being difficult to develop and to analyze. However, photographic film manufacturers, such as Kodak, Agfa and Fuji have produced several interesting emulsions successfully used by amateurs with 35mm cameras, often including cooling devices. The latent image decay effect producing a failure in the reciprocity law can indeed be reduced using cooling; unfortunately, this effect will be reduced by a different amount for the different emulsion layers, producing false colors. In addition, when analyzing a film, the so-called interimage effect should be taken into account [1]. These disadvantages made color films not very useful for professional astronomers, although they offer some definite advantages. The main advantage is the possibility of visualizing over a great number of pixels, beyond the present size of a big computer memory, the color effect distribution in two dimensions. Recently [2], the need of this three color representation has been emphasized in galactic evolution studies and some work conducted using image reconstruction techniques (both analog and digital), as well as using pictures obtained in conventional way. When a color emulsion is used, a second advantage over reconstruction techniques appears; all three color information is obtained simultaneously. This advantage is especially appreciated when objects are studied which change in time.

2. THE SPECIFIC FEATURES OF COLOR PHOTOGRAPHY SENSITOMETRY.

A lot of work has been already devoted to this question [1] [3], and we shall restrict ourselves to the essential characteristics of the method we used. Firstly, only reversal color film, like Ektachrome, will be considered. These films contain couplers [4] that are put into the emulsion layers during manufacture. These couplers form dyes during processing. Only one color developer is needed to produce simultaneously the three dye images in the emulsion layers, and the processing does not require elaborate chemical controls. Further, the transparencies produced can be duplicated on a suitable black and white panchromatic material (TRI X or Ektapan, for example) using filtered light, the original light being already correctly selected for color. Finally, these duplicates
can be analyzed conventionally with a microdensitometer. Table 1 gives the recommended Wratten filters [5] to be used for making different types of color separation. We used narrow-band separation filtering to produce the duplicates.

<table>
<thead>
<tr>
<th>Type of Work</th>
<th>Color</th>
<th>Blue</th>
<th>Green</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Photographs</td>
<td></td>
<td>47 B</td>
<td>58</td>
<td>25</td>
</tr>
<tr>
<td>Print</td>
<td></td>
<td>98</td>
<td>99</td>
<td>25</td>
</tr>
<tr>
<td>Narrow-Band</td>
<td></td>
<td>47 B</td>
<td>61</td>
<td>62</td>
</tr>
<tr>
<td>Separation</td>
<td>Very narrow-band</td>
<td>94 + 301</td>
<td>93 + 301</td>
<td>92 + 301</td>
</tr>
</tbody>
</table>

Table 1 - Wratten filters used to make different type of color separation when Kodachrome or Ektachrome films are used. W 301 is an infra-red rejecting filter which should be used when the densitometer gives a significant infra-red signal beyond 0.7 microns.

Obviously, our measured "equivalent B & W densities" are related to the so-called integral densities $d_I$ observed in each layer; these densities can readily be expressed as a linear combination of the so-called analytic densities, $d_A$ (see figure 1) by introducing the interimage coefficients $K_{ij}$. Here, we define the analytic densities as densities measured on a filtered duplicate when the color film is obtained by illumination from a quasi-monochromatic source with an effective wavelength situated near the maximum of sensitivity of each layer.

Then:

$$d_I^B = K_{11} d_A^B + K_{12} d_A^G + K_{13} d_A^R$$

$$d_I^G = K_{21} d_A^B + K_{22} d_A^G + K_{23} d_A^R$$

$$d_I^R = K_{31} d_A^B + K_{32} d_A^G + K_{33} d_A^R$$

(1)

We assume $K_{11} = K_{22} = K_{33} = 1$
These interimage coefficients can be deduced using measurements of

\[ d_i^j = f(d_A^j ; \ v_A^k = \text{cte}); \]

the slopes give \( K_{ij} \) and we easily compute \( d_A^i \) from the measured \( d_i^i \).
In figure 2, we see that $K_{13} \ll 1$ and $K_{33} \ll 1$. Because 3-color photometry is rather long, let us try to evaluate the precision of the direct method which uses integral densities of the layers interacting the least and corresponding to the blue and the red colors. We are interested by color effects which are readily described, for example, by the rate $E_B \times E_R^{-1} = f(x,y)$, where $E_B$ and $E_R$ are the blue and red exposures of the picture studied. As suggested by figure 1, we assume that the contrast coefficients $\gamma$ are the same in both colors and rewriting the system (1) more explicitly:

\[
d_I^B (x,y) = \log(E_B)^\gamma + K_{12} \log(E_G)^\gamma + K_{13} \log(E_R)^\gamma + G_{01}
\]

\[
d_I^R (x,y) = K_{31} \log(E_B)^\gamma + K_{32} (\log E_G)^\gamma + \log(E_R)^\gamma + G_{03}
\]
We deduce:

\[ d^B_I - d^R_I = \log(E_B \times E_R^{-1})^Y + (K_{12} - K_{32}) \log(E_B) Y + K_{13} \log(E_R)^Y \]

\[ - K_{31} \log(E_B)^Y + C_{01} - C_{03} \]  \hspace{1cm} (3)

As already stated, \( K_{13} \ll 1 \) and \( K_{31} \ll 1 \). Further, in figure 2, we see that \( K_{12} \approx K_{32} \) (this means that interimage effects produced by the green layer are almost the same on the red and on the blue layers). Finally, let us consider the part of (3) which is variable over the field, so:

\[ d^B_I(x,y) - d^R_I(x,y) \approx \gamma \log[E_B(x,y) \times E_R(x,y)^{-1}] \]  \hspace{1cm} (4)

Errors here are essentially due to the approximations we just made and they should be evaluated in each real case. They also depend on the adopted calibration procedure (see below). Clearly, interimage effects are considerably reduced when the colorimetric study is limited to the blue and red layers.

3. PRÁCTICAL USE FOR THE STUDY OF THE SOLAR CORONA.

The use of a color emulsion for the study of the solar corona during solar total eclipses has been found very effective [6] [7] for obvious reasons:

a) The "simultaneity" advantage is very appreciable, because the pictures should be obtained during a short event which, in addition, produces changes of the conditions of observations.

b) The low temperature component of the solar corona produces large color effects due to the line emission of low excitation states in well-known transitions.

c) The blue sky background dominates in the outer corona, producing a large color effect.

At the 1973 eclipse, we used several color films to record the corona [8], in high temperature conditions of an African site. The best photometric result has been obtained using the well known commercially available 18x24[cm²] Ektachrome film (sensitivity 50 ASA) produced by Kodak-Pathé in France, and standard E3 processing. To avoid any undesirable overexposure effects, we used a specially designed neutral radial filter to reduce the radial gradient of coronal intensities. Even the chromospheric emission features were correctly exposed. This kind of observation gave us the opportunity of studying a new type of very fine feature we named a "coronal spike" [7]. Coronal spikes were distinguished from their well known chromospheric counterparts, using colometric index type measurements, (see figure 3). High resolution studies appeared possible to the extent that the smearing function could be determined from the study of stellar
images in different colors, for example (see figure 3). Furthermore, we performed a colorimetric study of the dust component of the corona (F-corona).

![Diagram](image)

Fig. 3. The normalized spectral response $S_\lambda$ for the combination of the films, filters, instrument and terrestrial atmospheric transmission. Half width at half amplitude of the smearing "$\delta_{1/2}$" determined by the effects of chromatic aberration is shown. The positions of prominent chromospheric lines are indicated.

For this, we used accurately duplicated films in blue and in red light (see table 1), obtained with Ektapan 18x24[cm²] films. Simultaneously, on the same films, a duplicate of the 21-step wedge was printed. Indeed, this step wedge was produced from the image on the original Ektachrome film, at the same time as the coronal picture, using white light which approximately matches the integrated light of the studied picture (excluding the "low-temperature" component). Using this duplicated step wedge, we deduced 2 calibration-curves in standardly filtered integrated light. Referring to the deductions of § 3, one understands that interimage effects will be readily reduced as far as color effects are concerned; there only exist differential effects due to the differences in color index of the studied picture and the light used to obtained the step wedge (see figure 4).

Figure 5 shows the result of our colorimetric study of the F-corona (the F component was found from each duplicate using polarimetric measurements and the hypothesis of a white light K-corona), as compared with B & W studies of others authors; our study shows a good agreement in confirming the fact that in this range of wavelengths and radial distances, no color effects can be found.
Figure 4 - Three dimensional display of the distribution of photographic densities in the coronal picture as obtained by duplicating the original Ektachrome film using blue or red light, on a b & W film.
4. CONCLUSIONS

We showed that interimage effects which limit the precision of the photometry when filtered duplicates are used, can be considerably reduced if the study is limited to the blue and the red layers. In addition, using integral densities of the step wedges exposed to a light matching the spectrum of the studied image, a correct calibration is deduced. In any case, over exposure should be avoided. Taking into account these conditions, we think that the colorimetry of images such as images of planets, zodiacal cloud or comets should be successfully undertaken. These examples will be illustrated with projections.
REFERENCES


DISCUSSION

BAPPU: It is fascinating to see how clearly your pictures show that the coronal spikes are formations in the electron scattering corona. Have you any polarization observations that independently confirm this?

KOUTCHMY: We do have polarization measurements but, unfortunately, not with a resolution good enough to resolve these fine structures.