PART 8: PHOTOMETRIC MEASUREMENTS

1. Introduction

As we have seen, major information stored on the film concerns the position of meteors and reference stars. Furthermore, the film transforms certain amounts of light into different blackenings or densities. The creation of a photographic picture was described in detail in Part 1 Faint meteors. Film development suggestions have been given too, for instance in Part 2 on fireballs. Now we want to deal with a method to find out the brightness of a meteor from the photographic density along its trail. Such investigations were carried out many years ago (e.g. Millman and Hoffleit, 1937). The principles in these remain valid, of course, but the characteristics of the films have changed greatly. There are several general textbooks about astronomical photometry, for example Sterken and Manfroid (1992).

2. The image of star and meteor trails

Firstly, we must think about the differences between an image of a star and a meteor. This difference is enormous if the camera is guided. Then stars are appearing like points of various size, whereas meteors are trails. As we have already seen in the description of the photographic process in section 4.4 of Part 1 "Faint Meteors" (p. 15) and section 4 of Part 2 "Fireball Patrols" (p. 29), there are substantial differences if a grain of the emulsion is permanently lit by a faint source (star) or if it is exposed for a very short moment by a relatively bright meteor. In the case of guided photographs the magnitude determination of a meteor may be affected by a number of systematic influences as well. However, most meteor photographs are obtained by unguided cameras. In this case we compare geometrically similar features, i.e. trails caused by "moving light sources" of very much differing apparent velocity. Here we continue describing their analysis. In principle, the procedure is the same for all kinds of images.
The star image moves over the film with an linear velocity v_s dependent on its declination δ and the focal length f of the lens:

$$v_\mathrm{s} = v(\delta, f) \tag{1}$$

The nearer to the poles, the slower the star image moves:

$$v_\mathrm{s} = \frac{2\pi f}{T_\mathrm{sid}} \cos\delta \tag{2}$$

with $T_\mathrm{sid} = 86164$ s the Earth's sidereal rotation period. Consequently, the trails appear shorter and denser ("blacker"). Or, in other words, more fainter stars will become visible on the film.

Consequently, we have to reduce the star magnitudes m_r to a reference declination, say $\delta = 0°$. This provides the information what star at $\delta = 0°$would have caused the blackening S detected at the film. The difference in apparent magnitude $\Delta m(v)$ due to velocity v can be described by

$$\Delta m(v) = m_r(\delta = 0°) - m_s(\delta_s) = -2.5p \log \frac{v_r(\delta = 0°)}{v_s(\delta_s)} \quad (3),$$

where the parameter p is called the "Schwarzschild exponent" described in detail in Part 1 of this Handbook ("Faint Meteors"), p. 15. For common black and white emulsions we may assume p between 0.7 and 0.8.
Substituting eq. (2) for v_s, with $\cos 0° = 1$, we obtain

$$m_r(\delta = 0°) - m_s(\delta_s) = -2.5p \log \frac{1}{\cos \delta_s} \quad (4)$$

or, to calculate the "corrected magnitude" we need,

$$m_r(\delta = 0°) = m_s(\delta_s) - 2.5p \log \frac{1}{\cos \delta_s} \quad (5).$$

This fact must be considered when the characteristic curve is determined as described below (cf. section 5, the measurement and Fig. 8-2). If we refer to the magnitude of a comparison star m_s, we now mean its reduced value $m_r(\delta = 0°)$.
By contrast, a meteor causes only a very short exposure of each crystal on the emulsion. This leads to a much fainter image of the meteor trail. The difference $\Delta m(v)$ is

$$\Delta m(v) = m_M - m_s = -2.5p \log \frac{v_M}{v_s} \quad (6).$$

To make a photometric measurement means to determine the magnitude of a given object by comparing it with objects of known magnitudes. The main problem of meteor photometry is the comparison of star trails with very briefly exposed meteor trails.

3. The photometer

A photometer is a device which may

- measure the absolute density of parts of a photographic emulsion, or
- allow a comparison between the amount of light transmitted through the film and a previously defined transmission value (e.g. a grey cone).

The advantages of comparison measurements are considerable when compared with absolute measurements. There is no need to measure the precise amount of blackening as a figure, because we want to find out which amount of light along the meteor trail caused the same blackening like a certain star of another magnitude. Thus we need only the relative parameters for a meteor and reference stars. The most common photometers work after this principle.
Normally, there is a diaphragm into which you place the part of the film to be analysed. This diaphragm can be altered in size, so that the amount of light passing through the film can be changed until it equals the amount of the comparison light beam (Fig. 8-1). In this way you determine the "effective blackening" of the film, since a brighter object does not cause a "blacker" silver grain (which is impossible), but more blackened silver grains. In the case of very bright objects you will find an overexposure of a certain region of the film. This may cause shutter breaks to be smeared out or details of the fireball to be undetectable.

Furthermore, a shutter with a sector angle of $\alpha°$ reduces the blackening of the star trails by Δm(sh) since this exposes the emulsion only when the shutter does not cover the lens:

$$\Delta \mathrm{m(sh)} = \mathrm{m}_s - \mathrm{m}_{\mathrm{s,sh}} = -2.5 \log \frac{360°}{\alpha_{\mathrm{sh}}} \qquad (7).$$

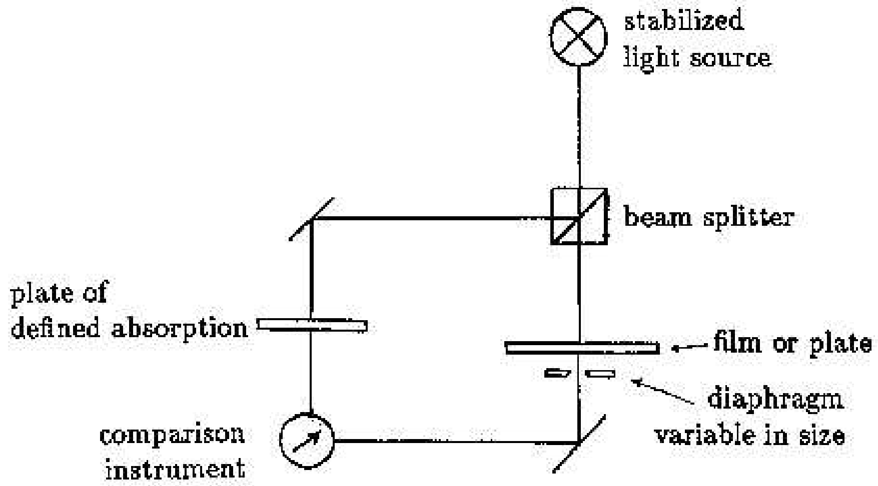


Figure 8-1: Principle of a photometer. The light beam of a stabilized lamp is splitted into two beams. One of these passes a filter of defined absorption, which can be adjusted for different purposes. The other beam passes the emulsion. Both amounts of transmitted light are detected at the comparison instrument. The size of the changeable diaphragm has to be changed until the both intensities are identical. This way we determine the "effective blackening" S (i.e. the intensity and size of the image) and the size of the diaphragm is the measure of S. Other principles, e.g. directly measuring the transmission of light, are also possible, but comparison measurements are to be preferred.

Then, we may calculate the ideal meteor magnitude $\mathrm{m_M}$ from a star trail showing the same blackening on the image, considering the meteor's angular velocity v_{M} and the shape of the shutter blades (their wing angle α):

$$m_{\mathrm{M}} = m_{\mathrm{s}} - 2.5p \log \frac{v_{\mathrm{M}}}{v_{\mathrm{s}}} + 2.5 \log \frac{360°}{\alpha_{\mathrm{sh}}} \qquad (8).$$

The "Schwarzschild-exponent" p plays an important role, but there are other effects to be considered. The light sensors in photometers may be photo resistors, photomultipliers, or other semiconductor receivers. Each of these sensors has a certain spectral range in which they work optimally. The lamps used for the transmission measurements are then chosen according to the characteristics of the sensor. Since only the photographic density of black and white films are measured, there are no changes in the spectral composition of the light after it is transmitted through the film. If you try to measure the brightnesses of objects from color materials, not only does the meteor trail have its own color, but also the colour may change along the trail. Furthermore, comparison stars showing different colors will create additional problems. Finally, color films itself do have a color "mask", which affects the light sensor of a photometer as well. Consequently color films must not be used for photometry.
Of course, the color differences of comparison stars cause some differences on black and white films, too, but knowing the color index of the stars used and the behaviour of the film–lens combination, it is possible to calculate precise V-magnitudes, as described next.

4. Influence of object colors

As you may know, an object can appear at a different brightness in different ranges of the spectrum. For instance, Aldebaran or Antares as red stars are brighter in the red part of the spectrum than in

the blue part. Alternatively, Rigel as a "blue star" for example, appears brighter in blue than in red. Therefore, a system of magnitudes was defined by the *IAU*, differentiating between U (ultraviolet), B (blue), V (visual, or yellow), I (infrared), as well as further infrared regions ($J, H, K, \ldots$). Thus the color of a star or other object can be described by the difference of its brightness in different, neighbouring spectral channels. This is called the color index. The most frequently used color index is the $B-V$, e.g. the difference of the blue and the visible (yellow) channels. According to the definition of the magnitude scale, $B-V>0$ characterizes a "red object", $B-V<0$ is a "blue object".
For our purposes the V magnitude is of main interest. Most black and white films give V to a good approximation without applying additional filters. Several combinations of common black and white films and filters have been tested and the differences to the V-magnitude were found to be negligible, especially if it is possible avoid to using comparison stars of intense red colour (values of $B-V$ larger than 0.7). It was found that meteors have a negative $B-V$ color index (Hajduková, 1974).

5. Measurement

Before starting with the photometry of the meteor trail, we must choose a number of reference stars. We should avoid double stars, i.e. all stars which are not clearly separated with the lens used. The reference stars should cover a wide magnitude range, since we need them to construct a characteristic curve for the film. If possible, we choose stars in the vicinity of the meteor trail. Then we avoid errors due to differences in sky conditions. If the time of the meteor's appearance is known, we should refer to the point of the star trail which was exposed at that moment. Otherwise, we may measure near the middle of the star trail. Each measurement should be repeated about 3 to 5 times in order to find the accuracy of the obtained value. Thus we get a number of points defining a density-magnitude relation (Figure 8-2), where m_s is the reduced star magnitude according to eq. (5). Next we start measuring the meteor trail. This procedure depends on the photometer. If a device for scanning is available, we can adjust the negative so that only the trail is scanned. In the case of wide angle or fish eye images, the meteor trails may be curved, and we have to adjust the negative after examining short parts of the trail. Care must be taken with this as we are trying to obtain a magnitude profile along the path, so the measurement should be done as continuously as possible.

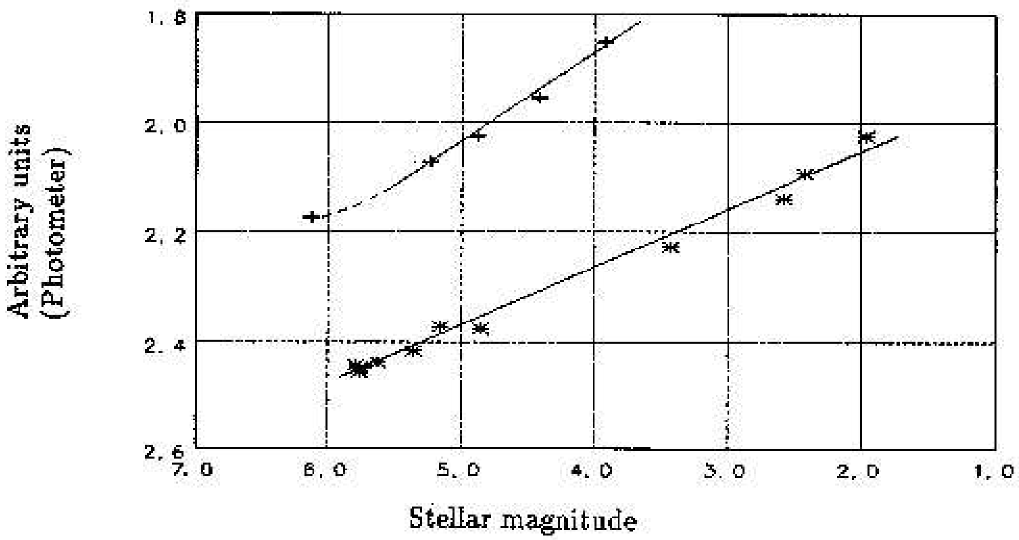


Figure 8-2: Construction of a characteristic curve from photometry of reference stars. The magnitudes have to be corrected for different declinations of the stars according to eq. (5).

If no scanning equipment is to hand, we need adjust the trail so, that a shift in one coordinate only will allow the following of the trail. Then we must measure point by point, shifting the measuring table in between each measurement. It is not easily possible to recommend a step width for this procedure, however, it should be short enough to separate all the characteristic features of the brightness variations. On the other hand, the resolution of the emulsion is of the order of $20 \ldots 50\mu$m, and the step width may be longer than this.
The measured densities may then be transformed into relative magnitudes. After this we have to apply the above-mentioned formulae to calculate the true meteor's magnitude. As a rough guess, we may expect the meteor to be about 7^{m} brighter than a reference star causing the same photographic density.

6. Peculiarities of meteor trail photometry

Photometric methods have been primarily developed for stars, and thus for point-like objects rather than for trails. The kind of diaphragm in the photometer is also of importance. If your photometer does not use a circular diaphragm, you must ensure that the orientation of the trails is comparable for each trail, whether of star or meteor. The main point is to use always the same orientation (Fig. 8-3).

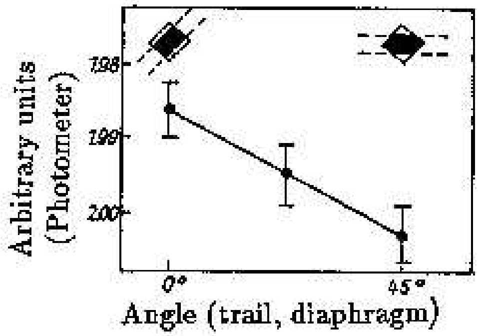


Figure 8-3: Influence of the orientation of the star trails in the measuring square diaphragm of a photometer. It is necessary to always use the same orientation for the entire photometry of both stars and meteor trail.

If we look at the intensity of the blackening of star trails on long exposure photographs, we may find that they differ from the beginning towards the end. Initially, the film's sensitivity seems to be larger. Obviously, there is some influence of the pre-exposure to the sky-background later in the trails, and from this we would expect also that meteors appearing at the beginning of an exposure appear brighter than others appearing later in the exposure. If the background density of a film is greater than $D = 0.1$ then the meteor has to be brighter to be detected. Malmström (1985a) points out that this phenomenon is sometimes, erroneously, called the "loss in film sensitivity" or "reciprocity failure". In reality it is a loss in the low intensity part of the dynamical range of the emulsion. The change in limiting magnitude $\Delta \mathrm{m}_p$ for trailed point sources, stars or meteors, with increasing sky density is:

$$\Delta \mathrm{m}_p = \frac{(D - 0.1)}{-0.32}$$

where D is the background density on the plate (Malmström, 1985b). For a 4-hour exposure the limiting magnitude of trails decreases by about 1^{m} to 2^{m} for background densitites between 0.5 and 0.7 which easily occur on fireball patrol photographs obtained at average sites. This difference $\Delta \mathrm{m}_p$ increases after about 1 hour (Fig. 8-4, right diagram). If the time of the meteor's appearance is known, we should compare the meteor trail density with that of the star trails recorded at the same time.
Note that this phenomenon will not occur with short exposures. For example, there was no effect

measurable on 10-minute exposures (Fig. 8-4, left diagram; Rendtel, 1979). Also Russell (1986) found that the effect is less important than described by Malmström (1985). According to his investigation, changes in the distance from the field center and extinction have a larger effect.

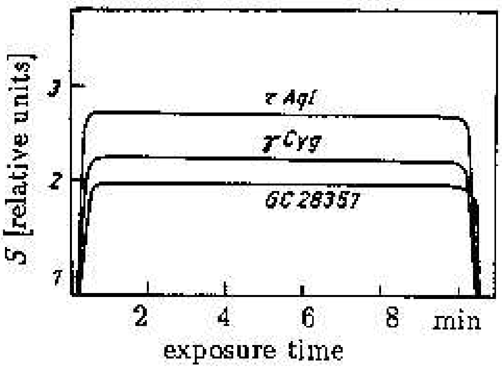
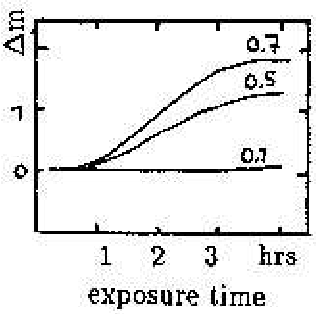


Figure 8-4:
Photometry along star trails at 10-minute exposures. During this exposure duration no pre-exposure effect can be detected (Rendtel, 1979).



For much longer exposures the situation may become different: Malmström found a decrease of sensitivity (Malmström, 1985a), expressed in loss of limiting magnitude Δm. The effect is strongest for high density (i.e. "black" plates).

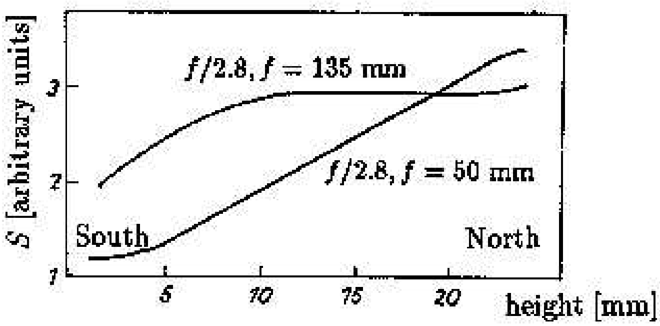


Figure 8-5: Change in background over the photographed field at the meridian (South is down, North is up). The effects are larger for wide angle lenses.

Generally, any background exposure leads to a decrease in the signal-to-noise ratio of the signal measurements resulting in the loss of often faint meteor trails. Another effect of background illumination (Furenlid *et al.*, 1985) may be ignored in most cases, as it can be expected to be of the order of only $0\overset{m}{.}2$. It arises from the different colors of the meteor and the background and the use of one characteristic curve for reduction of photometric measurements. The magnitude of this kind of error is, in practice, unpredictable. Night sky brightness varies with time, and color varies due to a host of factors (twilight, moon, local conditions). For example, the Full Moon has the color of a K0V-star, with $U - B = 0.45$ and $B - V = 0.91$.

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