PART 4: METEOR TRAINS

1. Introduction

Bright meteors, particularly fireballs, often leave an “afterglow” along their trail, called a train. Such trains have been described extensively in the past (e.g. Beech, 1987). High velocity cometary-type meteors especially produce persistent trains, but little is known about the mechanisms behind these phenomena.

When a meteoroid enters the Earth’s atmosphere its surface atoms sublimate and are turned into ions through collisions with atmospheric particles, which will themselves be ionized simultaneously. Ions of both the meteoroid and the atmosphere are then present along the trajectory. While most of these atoms exist in excited states for about 10^{-8} seconds only, there are also some atomic states that may persist for times longer than several seconds (so-called metastable levels), perhaps associated with some molecules (N_2, NO, NO_2, …?).

These appear bright against the night sky. However, much mystery still surrounds the physics of train phenomena (Ceplecha, 1991).

A large meteoroid entering the atmosphere also distributes a substantial amount of material along its trajectory as it ablates. This may lead to the formation of the so-called smoke trains, which do not emit light, and are composed of dust particles.

Both types of trains occur at altitudes above 20 km. At these heights strong winds exist that will cause the trains to distort within a short period after formation. Thus observations of trains also may yield information about the upper atmosphere as well as about the amount of material brought into the atmosphere by the meteoroid.

2. Photography

2.1. Regular trains

Ceplecha Even regular meteor observers are surprised by bright meteors or fireballs. Normally data about the brightness, time of occurrence, colors, and perhaps sound of a fireball are recorded in detail. Only for very bright and/or long enduring trains might someone think to take photographs of the train.

To secure a train on film you might try the following while you are visually observing. Keep a camera with a high sensitivity film (cf. section 4 of Part 1: Faint Meteors) and a very fast lens with an already-opened shutter near at hand, protected from exposure by a suitable cover. When a bright event leaving a train occurs, you remove the cover and expose the film for about 20 ... 40 seconds. For very bright and long enduring trains, take a series of photographs to record the variations in brightness and shape. Each exposure should be between 10 and 30 seconds long. Guiding the photographs is not necessary. Generally, observers are not prepared in the manner we have just described, so chance plays a major role.

Some instructive examples are presented in Hirose *et al.* (1967), p. 110, in Cook and Hughes (1957), in Keller and Schmidbauer (1988) and also in the Part 10 of this handbook (Fig. 10-12).

Experiments conducted during the 1989 and 1991 Perseid shower suggested there were very few meteors leaving suitably bright trains that could be photographed. As a result, the time for the operator to remove the cover from the lens was comparable to the duration of most of the trains. As already mentioned, train photographs of very bright fireballs, the trains of which were visible for minutes, do exist.

2.2. Smoke trains

Since smoke trains do not emit light, they appear dark, thus they are not visible in the night sky. There are two possible ways of observing them.

First, they may be visible accompanying daylight fireballs as *smoke trains.* Of course, it is not feasible to establish a regular survey for daylight events, but if you do accidentally see a bright fireball during the day, you should note if this kind of train is formed, and if so try to photograph it. In this circumstance, the rules of "normal" (daylight) photography are valid, and no special instructions are necessary. To be sure that the structures in a daylight smoke train are measurable, take photos with different exposure times, both over- and underexposing the image.

The second way of seeing such trains occurs in twilight (Fig. 4-1). Since smoke trains appear below 80 kilometers altitude, they are still lit by the Sun, even in late twilight. Consequently, they appear bright. The conditions for the visibility of smoke trains as sunlit clouds after sunset or before sunrise are similar to those for noctilucent clouds.

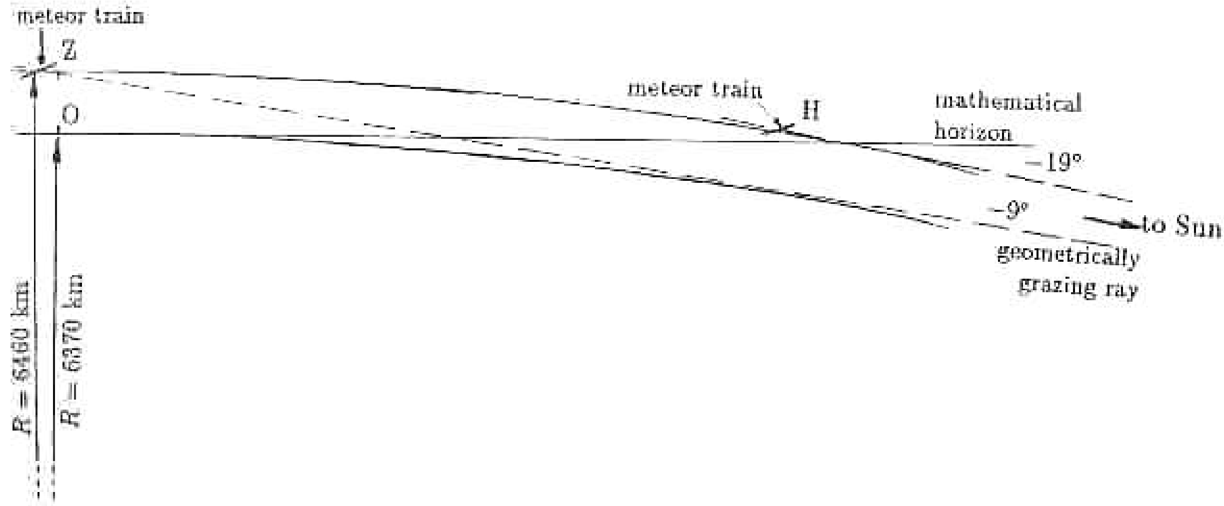

Figure 4-1: Higher altitudes in the atmosphere are still lit by the Sun even when it is below horizon, causing twilight phenomena and also illuminating noctilucent clouds (at $h = 83$ km) and smoke trains left by meteors. The figure does not consider atmospheric refraction, which increases the duration of visibility somewhat (cf. Gadsden and Schröder, 1989, pp. 149–153). Geometrically, with the Sun being 9° below the horizon, the zenith Z of the observer at O is still lit by direct sunlight, while at a depression angle of 19° a near-horizon area (around H) receives sunlight.

Noctilucent clouds are frequently seen at latitudes north of 50°N during the period May-August as well as south of 50°S in the months of November-February. These clouds are situated at a mean height of 83 km. For the clouds to receive sunlight, the sun must not be more than 16° below the horizon at this altitude. The diagram shows the time interval during the night on different months when the depression angle of the Sun permits these clouds to be visible for three different latitudes (Fig. 4-2). These times correspond roughly to the periods at night when smoke trains may be lit, so you can find which times permit observations of smoke trains in the region of the twilight arch.

If a smoke train is observed you may make a series of exposures of about 10 . . . 20 seconds duration (depending on the brightness of the sky and the train). If you are not sure about the optimal exposure time to use, try several, but not less than 3 seconds and not longer than 2 minutes. In choosing film types, high sensitivity films are ideal as they keep the exposure times short. If the exposure is too long, the shape of the train will distort during the exposure and the image of it will appear blurred. It is then hard to measure structures contained in the train.

Both types of trains were recently observed accompanying a daylight fireball which appeared shortly before sunset, with the trains visible at heights between 30 and 10 km (Ceplecha, 1991). An excellent example of a very bright smoke train observed in the twilight, is reproduced in Part 10 (Fig. 10-13).

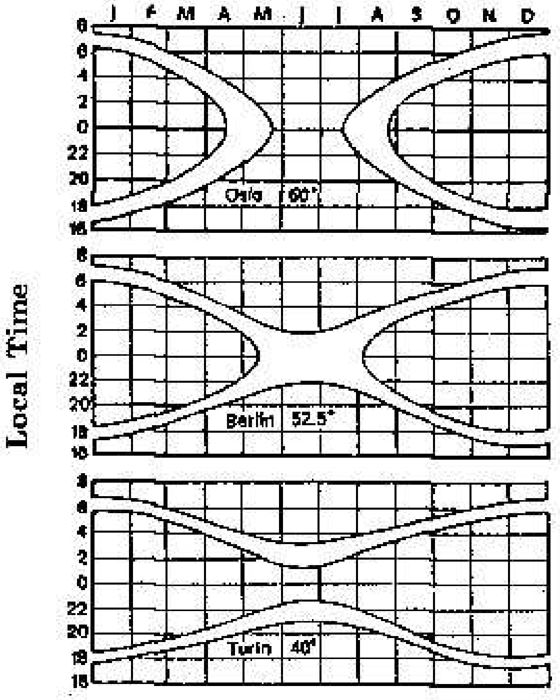

Figure 4-2: Diagram of the visibility of noctilucent clouds which occur at an altitude of ≈ 83 km. During the indicated twilight period (white) the Sun is between 9° and 18° below horizon. This is also the most favourable time interval for the observation of sunlit fireball trains.

The same diagram, shifted by 6 months, is valid for the same latitudes in the southern hemisphere. For $\varphi \geq 65°$ and $\varphi \leq 40°$ the time spans for effective observations are short.

3. Equipment

The *equipment* required to photograph trains is different depending on the train type.

3.1. Regular trains at night

1. camera with a very fast film and lens
2. shutter already open, but covered (e.g. by a dense piece of cloth)
3. when a bright meteor appears and leaves a persistent train you remove the cover and expose the frame for a length of time dependent on the brightness of the train (at least 20 . . . 40 seconds)
4. if the train lasts for more than one exposure, continue with exposures of about the same duration.

3.2. Smoke trains in daylight

1. "normal" daylight photography; slight underexposure may be best
2. try to make a series of photographs and note the time of appearance of the fireball (if seen) as well as the time of the train exposures.
3. note azimuth and zenith distance of the train.

3.3. Smoke trains during twilight

1. camera with a fast lens and film
2. try to make several exposures of different durations, depending on the film and lens used(try at least 10 . . . 20 seconds)
3. note the time of the fireball's appearance (if seen) and the time(s) of the exposures taken.
4. note azimuth and zenith distance of the train.

4. Use of a video camera

These phenomena can also be recorded with a video camera. The dust trains in daylight or twilight do not require special hints. One advantage of a video camera over a still camera is the time mark which is included on each frame. Even if the time is not precisely adjusted to a time signal, you will still record the relative time scale of the changes within a train.

Regular trains during the night may be much more difficult to record because of their faintness.

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