CHAPTER 1

Introduction

Most people have seen a ring around the moon. Fewer notice its daytime counterpart around the sun, even though it is common. And few indeed have ever seen a display of concentric rings like that witnessed by Helmut Weickmann, observing from the open cockpit of his Henschel reconnaissance plane over Germany in 1940. Weickmann's diagram of the display is reproduced in Figure 1.1, and the following is an excerpt from his notes on the display, written as his plane climbed through thin clouds. The 22° halo that he refers to is just the daytime version of the ring around the moon mentioned above.

> 5000 meters. Haze in the south, probably representing the lower boundary of the cirrostratus, intense 22° halo is visible in it, becoming increasingly clear.
>
> 6300 meters. …cirrostratus with two more concentric rings round the sun.
>
> 7700 meters. The halo phenomenon has increased still more by three more rings. All the rings are clearly red inside and bluish to white at the outside. (Weickmann [86, page 67])

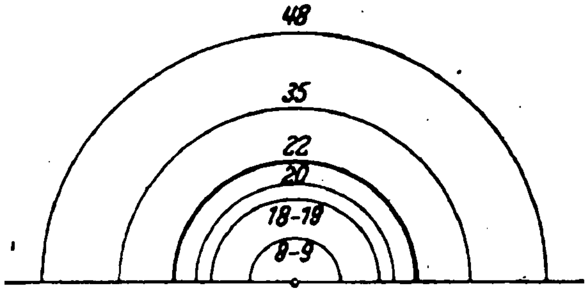

FIGURE 1.1 Weickmann's diagram of his odd radius halo display in 1940. Each semicircle represents a halo. The numbers are Weickmann's estimates of the angular distances of the halos from the sun. (From Steinmetz and Weickmann [72])

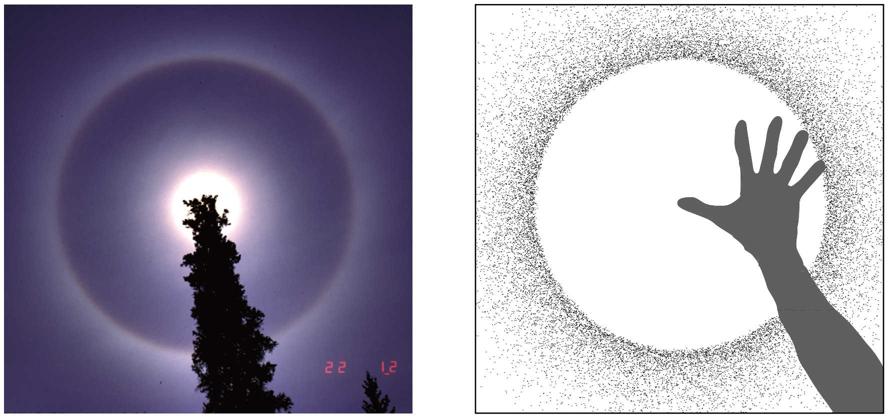

FIGURE 1.2 The 22° halo. With your arm extended and fingers spread, the angular distance from thumb to pinky is about 22°, the same as the angular radius of the halo.

Weickmann was seeing atmospheric halos. The numbers on the rings in his diagram are his estimates of the angular radii of the halos. To get some feeling for these angular distances, you can extend your arm completely and spread your fingers; the angular distance from thumb to pinky finger will be very nearly 22°. The angular radius of the 22° halo is also 22°, as you might guess. So if you cover the sun with the tip of your thumb—still with the arm extended and fingers spread—then when the 22° halo is present, the tip of your pinky finger will be on the halo (Figure 1.2).

You will find, once you begin to look for halos, that they are surprisingly common. But you will also find that when you see a circular halo and measure its angular radius, the halo almost always turns out to be the 22° halo; other circular halos are more or less rare. Nevertheless, when the 22° halo is bright and uniform, try looking for a much larger circular halo. If successful, you are probably seeing the 46° halo. Its angular radius is 46°, more than twice that of the 22° halo. The 22° halo is itself big, but the 46° halo is enormous. Its size and its typically low intensity make it easy to miss, but dedicated observers might see the 46° halo a handful of times during the year. Probably the largest halo in Weickmann's diagram was the 46° halo.

Halos are due to ice crystals in the atmosphere. The crystals that make good halos are usually shaped like tiny hexagonal prisms. Such crystals can make a 22° halo and a 46° halo, and they can therefore account for two of the six halos that Weickmann reported. But they cannot account for the other four, and this is what makes Weickmann's observation special. These four halos are the wrong size, that is, their radii are neither 22° nor 46°. They are "odd radius" halos.

The main objective of this book is to tell the story of odd radius halos. There are many of them, not just the circular halos like those that Weickmann saw. Weickmann himself, together with his colleague Hermann Steinmetz, got the story right, according to current thinking, and much of our book will be an elaboration of their basic explanation. But before tackling odd radius halos we will want to tell some of the fascinating story of halos in general and of the ice crystals that cause them. We will see that there is a rich variety of halos, and that at times they can be stunningly beautiful. The beauty in the halos is very much a manifestation of the beauty in the ice crystals that cause them.

Why should anyone care about halos, and why especially should anyone care about odd radius halos? In general, halos have something to tell about the atmosphere where they form. The fact that halos are better in Antarctica than elsewhere suggests that there is something special about the Antarctic atmosphere. (What it is, we do not know.) Similarly, any halos on Saturn's moon Titan would provide some clues about the composition of the Titan atmosphere. It was for precisely this reason that the Huygens probe looked for halos as it descended into Titan's atmosphere in January of 2005.[1]

But such practicalities are not what drives most halo watchers, and they are not what drives us. So instead of practicalities we offer you aesthetics, and we offer you the excitement of the chase. We invite you to watch for these lovely phenomena and, if you are so inclined, to record and photograph what you see. The field of halos is an area of science where anyone has a chance to contribute. Nobody knows where the next great halo display will occur.

Four common halos

Let's begin with four common halos: the 22° halo, the parhelia, the circumzenith arc, and the tangent arc.

The 22° halo We said that the 22° halo is common. In many parts of the world it is visible about 100 days per year, either at night around the moon or in the daytime around the sun. If you have not seen the daytime version, it is probably because you have not looked for it. But if you have looked for it and still not seen it, it may be because you are looking too close to the sun. In the sky the angular radius of 22° feels big, somehow much bigger than what the spread finger method suggests when you apply it sitting in your armchair indoors. So the 22° halo is really nowhere near the sun. When you eventually see it and try to photograph it with a standard camera lens, you will find that the lens is not up to the job, and that it captures only a part of the halo. Most of the halo photographs in this book were taken with wide angle lenses. Such lenses compress everything, including the halos, thus making the halos look unrealistically small.

Sometimes the 22° halo is bright, sometimes it is barely discernible. It is usually

[1]At the time of this writing, no halos had been detected in the Huygens data, but the data were still being analyzed. Können [41] has speculated on the sorts of halos that might occur on Titan.

FIGURE 1.3 Parhelia at left and right and circumzenith arc at top. Like most of the photographs in this book, this photograph was taken with a wide angle lens, which compresses the halos and here makes the circumzenith arc look too low. The arc is in reality nearly overhead. South Pole, December 10, 1998.

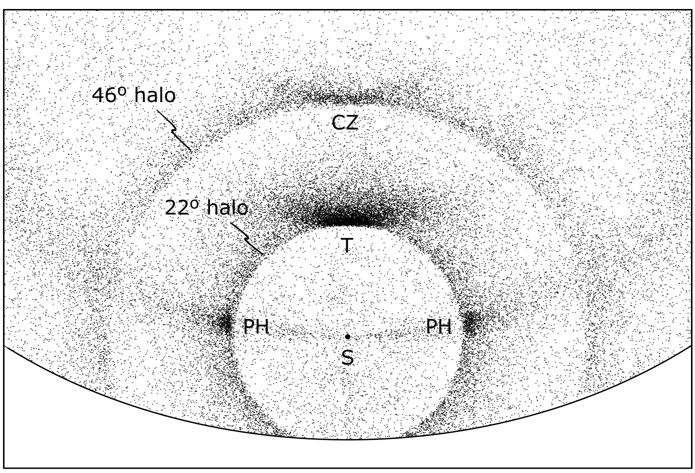

FIGURE 1.4 Computer simulation of a rather ordinary halo display. Of the halos shown here, only the 46° halo is at all uncommon. **S** = sun, **PH** = parhelion, **CZ** = circumzenith arc, **T** = tangent arc.

colored, but rarely are the colors pronounced. Most often the halo will be colored a rather nondescript orange-brown on the inside and then white on the outside, with at most a suggestion of other colors in between.

Parhelia The parhelia, or sundogs, are almost as common as the 22° halo. They appear as two patches of light to the left and right of the sun (Figure 1.3). Their angular distance from the sun is 22° or a bit more, so when the 22° halo and parhelia occur simultaneously, the parhelia will be on or just outside the 22° halo. In fact, the parhelia often appear simply as enhancements of the 22° halo at left and right. Some parhelia show rather good spectral colors, with red on the inside—the sun side—and blue on the outside. Other parhelia can be entirely white, especially when the sun is high.

Circumzenith arc The next time that you see a parhelion, look at the sky high overhead. If the sun elevation is right, say 15° to 25°, and if the cloud that is making your parhelion extends to the neighborhood of the zenith, you are apt to see the circumzenith arc as well (Figure 1.3). It can be glorious—bright with spectacular spectral colors—but few people outside the halo community ever see it, not because the arc is rare, but because people rarely look up. We predict that you will see the circumzenith arc about 25 days per year if you watch for it.

Tangent arc Another common halo is the tangent arc. When accompanying the 22° halo, the tangent arc is outside the 22° halo but tangent to it on top and bottom. When the arc is well defined, it has a distinctive and lovely shape that changes dramatically with sun elevation. More often, though, the tangent arc will appear only as a vaguely defined region of illumination at the top or bottom of the 22° halo.

Although the tangent arc is technically a single halo, at low to moderate sun elevations it consists of two separate components known as the upper and lower tangent arcs. For low sun the lower tangent arc is of course below the horizon, and so what is normally seen then is just the upper tangent arc. At moderate and higher sun elevations the upper and lower tangent arcs do indeed merge and form one halo, the so-called circumscribed halo.

Figure 1.4 is a computer simulation of a halo display consisting mainly of the above four halos—the 22° halo, the parhelia, the circumzenith arc, and the tangent arc. The display is a bit better than average, but it is far from being a great display. To begin to appreciate how a better halo display might arise, you need to know something about the falling modes of ice crystals.

The way the crystals fall

We said that the crystals that make halos are usually in the shape of hexagonal prisms. These prisms can range from short and squat to long and thin; the former

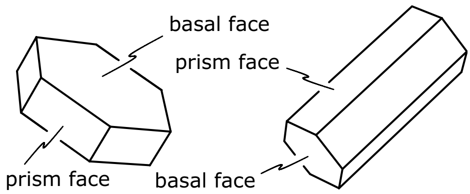

FIGURE 1.5 (Hexagonal) plate and column crystals. Each crystal has two basal faces and six prism faces

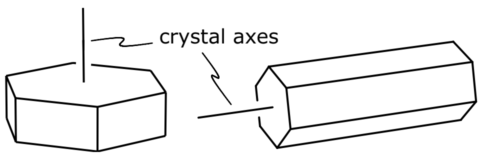

FIGURE 1.6 (*Left*) Oriented plate crystal. The basal faces of the crystal are horizontal, but there are no other constraints on the crystal. (*Right*) Oriented column crystal. The crystal axis is horizontal, but there are no other constraints.

are called (hexagonal) *plates,* the latter are (hexagonal) *columns* (Figure 1.5).

The shapes and sizes of crystals influence the way that the crystals orient themselves as they fall through the air. Plate crystals often tend to fall with their basal faces horizontal; such crystal orientations are called *plate orientations,* and the crystals are called oriented plates. Column crystals often tend to fall with their axes horizontal; these orientations are *column orientations,* and the crystals are oriented columns. Oriented plates and oriented columns are falling so as to maximize air resistance. Sometimes, however, air resistance seems to produce no special orientations, and the crystals fall with more or less random orientations. Plate orientations, column orientations, and random orientations are the three common falling modes for ice crystals.

It is not obvious that the crystals should tend to fall in these three ways. Nineteenth century scientists, in fact, had the plate and column falling modes reversed, with the crystals orienting so as to minimize air resistance and thus knifing through the air as they fell. We still do not understand in detail the relation between crystal size and shape on the one hand, and falling mode on the other. In an effort to do so, people have tossed nickels into swimming pools and watched them sink, and they have dropped large styrofoam crystal models from rooftops. Other people have approached the problem more theoretically. But the truth is that nobody knows for sure how a tiny, nearly invisible ice crystal will fall. Some of the most convincing evidence for the existence of the three classes of crystal orientations—plate orientations, column orientations, and random orientations—comes from halo observations, as we will see later.

The existence of different crystal orientation classes makes for a rich variety of halos, because each orientation class gives rise to its own characteristic halos. The parhelia and the circumzenith arc arise in oriented plate crystals, the tangent arc

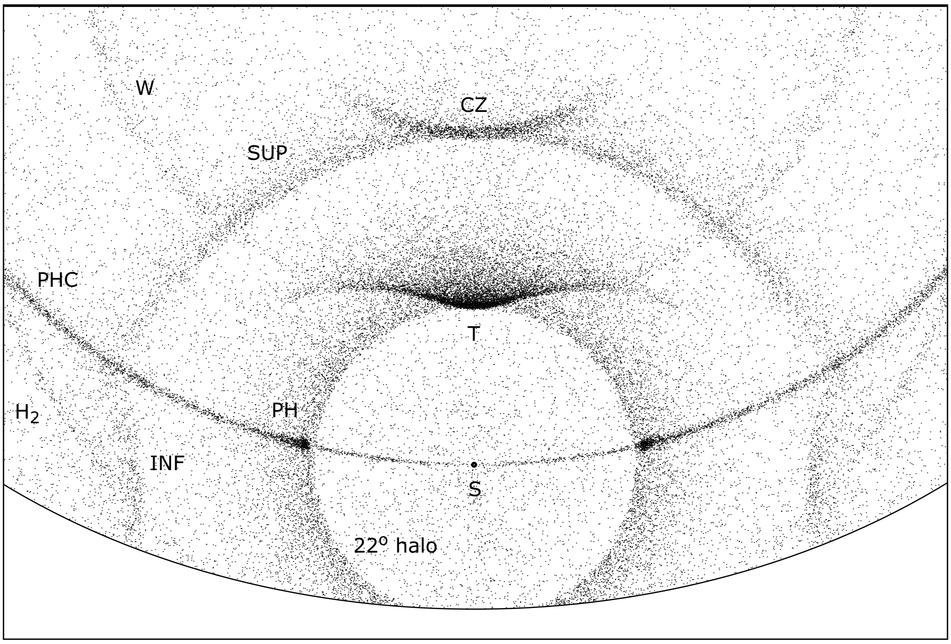

FIGURE 1.7 Computer simulation of a good halo display. The instructions given to the computer to make this simulation were the same as those for the simulation in Figure 1.4 except that here the tilts of the crystals were made much smaller. (The tilts of the randomly oriented crystals were not changed.) Smaller tilts result in more and better halos. **S** = sun, **PH** = parhelion, **CZ** = circumzenith arc, **T** = tangent arc, **INF** = infralateral arc, **SUP** = supralateral arc, **W** = Wegener arc, **PHC** = parhelic circle, $\mathbf{H_2}$ = subhelic arc.

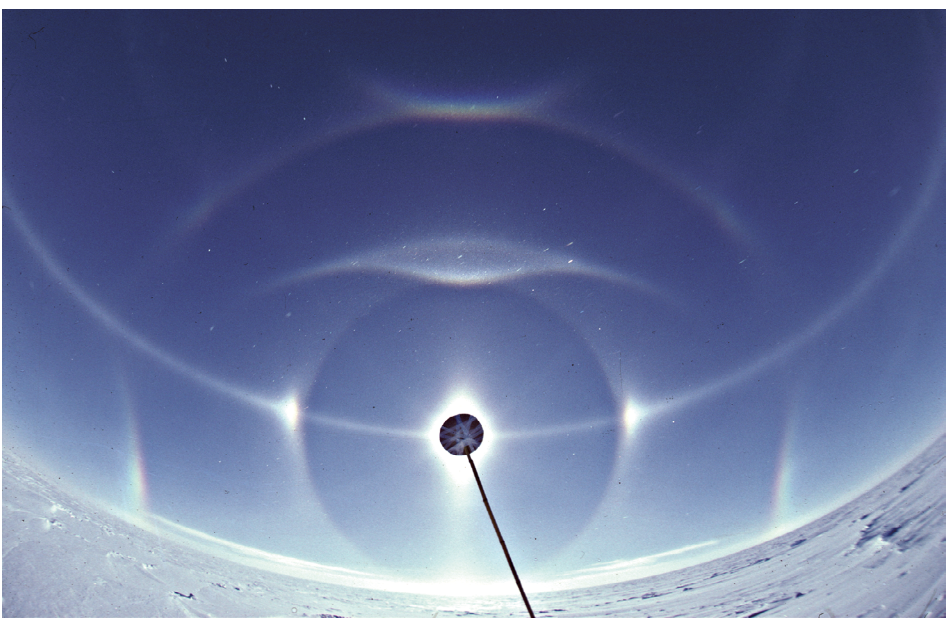

FIGURE 1.8 Halo display, South Pole, January 2, 1990.

arises in oriented column crystals, and the 22° halo arises in randomly oriented crystals.

Crystal orientations are of course never perfect. Oriented plates and columns, rather than being perfectly horizontal, are apt at any given moment to be tilted through some small angle. The tilt will vary from moment to moment and from crystal to crystal.

In the everyday halo display, the tilts of the crystals are not especially small. In the simulation in Figure 1.4, for example, the tilts were a few degrees or so. (We are talking about the oriented plates and columns, of course—not the randomly oriented crystals.) That may sound small, but much smaller tilts are possible. As the tilts of the crystals become smaller, the common halos become brighter and more sharply defined, and rare halos, not visible in ordinary displays, begin to appear. In the best halo displays, the tilts of the crystals seem to be, almost incredibly, less than half a degree. These are the displays that the halo enthusiast dreams of, when the sky is filled with arcs of every description (Figures 1.8, 3.7, 6.7, 6.8).

Thus, one way to get uncommon halos is for the orientations of the oriented plates and columns to be uncommonly good, that is, for the crystals to be almost perfectly horizontal. Another way is for the crystals to take on uncommon falling modes—modes other than the common plate, column, and random modes (Chapter 6). A third way is for the halo-making crystals to occur in uncommon shapes—shapes other than hexagonal prisms. This turns out to be what was happening in Weickmann's display.