Unusual Solar Halos Over La Silla

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Most of the halo phenomena associated with the sun, or the moon, are caused by reflection or refraction of light in ice crystals which are hexagonal in cross-section, usually in cirrus-type clouds. The amazing variety of halos produced by these simple crystals is nicely explained in Greenler's book "Rainbows, halos and glories".

Halos are not infrequently seen over La Silla and, from time to time, interesting displays may be recorded like the series of pictures in Figure 1 which illustrate the evolution of a brightly coloured circumzenithal arc as the sun progressively sets down.

On January 27, 1990, we had the chance to photograph a rare and impressive combination of solar halos. The phenomenon appeared around 2 p.m. and lasted less than 1 h. It is partly illustrated in Figures 2 and 3, the different halos being identified in Figure 5. The coloured ring around the sun is the 22° refraction halo. It is particularly sharp and remarkable for its brightness and high contrast. Downwards, we successively encounter a part of the great 46° halo and the relatively rare circumhorizontal arc well detached from the former. Despite being fainter, both were significantly coloured. The striking feature was the small parhelic circle inside and tangent to the 22° halo. This halo surrounding the zenith and passing through the sun is due to reflected sunlight, as indicated by its whitish colour. Parallel to the horizon at the solar elevation, it is generally much more extended across the sky (see Fig. 8); as far as we know, this is one of the smallest parhelic circles ever reported (Cardon, 1977, discussed the observation of an unusual paraselenic circle whose diameter is comparable to that of the 22° halo). The peculiar aspect of this halo combination is due to the fact that at the moment of observation, the zenithal distance of the sun was exactly half the angular radius of the 22° halo, a situation which cannot occur at any latitude nor at any moment. After a few hours of interruption, the phenomena continued until sunset with the progressive apparition of the sun dogs and the circumzenithal arc. Figures 4 and 6 illustrate the complex of halos, unfortunately fainter, for a sun elevation of ~36°: the parhelic circle is much more extended. Two sun dogs are also present, located on the parhelic circle and well detached from the 22° halo.

It is quite remarkable that all the phenomena described before may be

Figure 1: *From top to bottom, this sequence of photos, obtained on February 20, 1990, illustrates the evolution of the circumzenithal arc as the sun progressively sets down. The circumzenithal arc is a refraction halo which appears around the zenith, high in the sky, and only for a sun elevation lower than 32° (see Fig. 8). It is one of the most brilliantly coloured halos caused by ice crystals, the purity of its colours often surpassing that of the rainbow. This occurs because the circumzenithal arc is not caused by a minimum deviation effect like for other halos (Fig. 7).*

Figure 2: *The 22° halo and, inside, the very unusual parhelic circle photographed for a sun elevation of ~79° on January 27, 1990, about 2 p.m. local time. The colours indicate that the greatest halo is due to refraction while the parhelic (whitish) circle is due to reflected sunlight.*

Figure 3: *The lower part of the halo complex illustrated in Figure 2. It was recorded at the same moment. In addition to the 22° halo, we can identify a portion of the 46° halo and the circumhorizontal arc.*

explained by the presence in the atmosphere of only one type of ice crystals: the plate-form crystals; pencil-shaped crystals if present would have produced additional halos like the circumscribed halo or the upper tangent arc (Greenler and Mallmann, 1972). The presence of a portion of the great 46° halo also suggests that plate crystals dominate (Plattloch and Tränkle, 1984). Figure 7 illustrates the different light rays which may explain the observed halos; most of the phenomena are in agreement with the simulations of Greenler et al. (1979, 1980). For the unusual parhelic circle seen in Figure 2, we have computed the theoretical brightness distribution along the perimeter. Fresnel formulae for reflectance times of the reflecting faces predict the intensity to be nearly constant along the perimeter except near the sun where it decreases to zero (see also Lynch, 1979). We find good agreement, but overexposition hampers a detailed comparison close to the sun. Finally, taking account of the angular diameter of the sun, the remarkable sharpness of the parhelic circle indicates that the oriented plate crystals producing it are aligned to better than 0.2°!

Apart from their aesthetic interest, observations of unusual halos or combination of halos may certainly contribute to a better understanding of ice crystal physics and ultimately one could hope to derive some characteristics of the atmosphere by simply analysing the observed halos. From the astronomical point of view, the halo phenomena may provide a unique tool for detecting crystals (not only ice) in planetary atmospheres (Whalley and McLaurin, 1984). This was first pointed out by O'Leary (1966) who suggested to measure the changes of Venus polarization near inferior conjunction when it passes the 22° scattering angle.

La Silla being located in a site where unique climatic conditions prevail and visited by many people equipped with

Figure 4: *The halo phenomena photographed a few hours later (about $5^h\,40^m$ p.m.) for a sun elevation of ~36°. The parhelic circle is now widely opened (see Figs. 6 and 8). Two parhelia or sun dogs are present, well detached from the 22° halo as can be expected for this elevation of the sun.* ▼

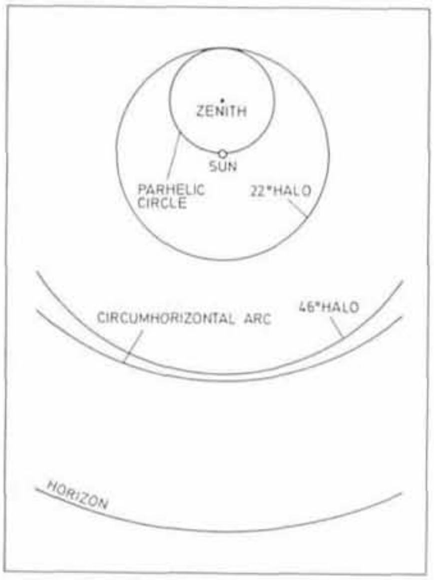

Figure 5: *Schematic zenith-centred projection illustrating the halo phenomena observed around 2 p.m. (Figs. 2 and 3).*

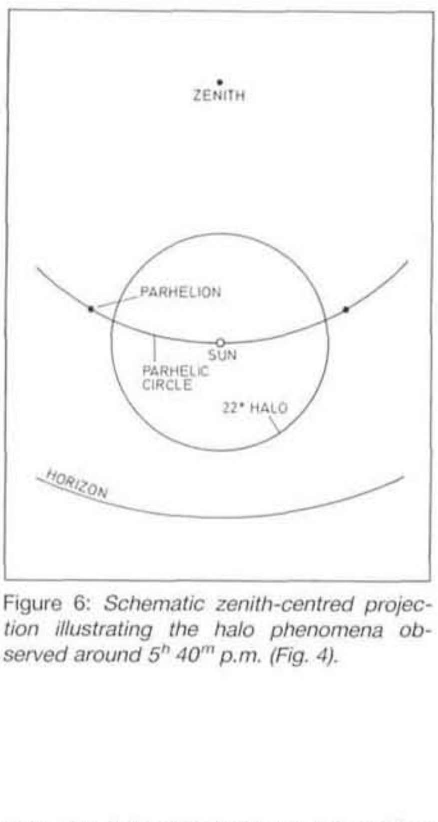

Figure 6: *Schematic zenith-centred projection illustrating the halo phenomena observed around $5^h\ 40^m$ p.m. (Fig. 4).*

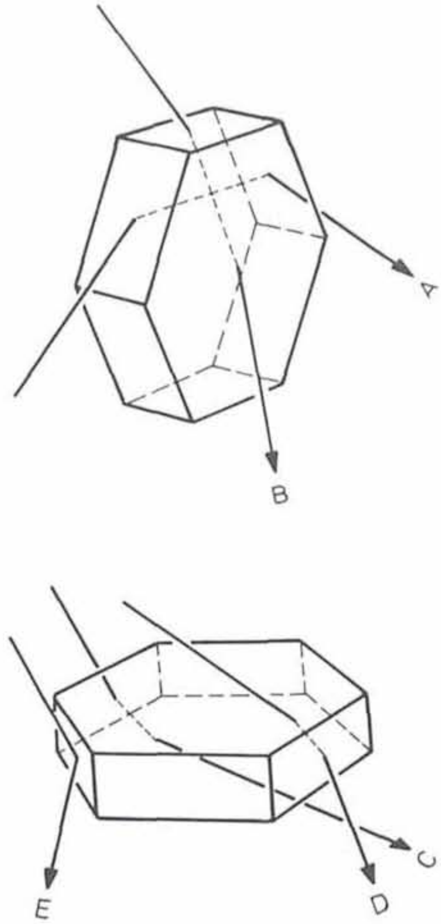

Figure 7: *This figure illustrates the light rays passing through plate-form hexagonal ice crystals which are thought to be responsible for all the halo phenomena observed on January 27, 1990. For the refracted rays A and B, the crystals act as 60° and 90° prisms, respectively. The light therefore concentrates near the minimum deviation, i.e., for ice, near 22° and 46°. If the crystals are randomly oriented in the sky, these rays are at the origin of the 22° and 46° ring halos. The shape of these halos is independent of the sun elevation. Falling in the air, some of these crystals, the largest ones, tend to have their flat bases oriented horizontally. Through this subset of oriented crystals, rays of type A produce the light condensations called sun dogs or parhelia. For sun elevations close to 0°, the rays enter normal to the crystals and produce sun dogs located at the sun elevation on each side of the 22° halo. For higher sun elevations, the rays penetrate the oriented crystal with increasing skewness. The minimum angle of deviation through a prism being higher for skew rays, the sun dogs therefore appear detached from the 22° halo for moderately large sun elevations (Fig. 4). Interacting with the same subset of oriented crystals, the refracted rays C and D produce the circumhorizontal and circumzenithal arcs while rays E, reflected on vertical faces, are at the origin of the parhelic circle. For a given solar elevation, it is easy to realize that the light rays C, D, E apparently come from arcs or circles which are centred on the zenith and lie at constant elevation above the horizon (see Fig. 8), the only degree of freedom for the oriented crystals being rotation around their vertical axis. The parhelic circle passes through the sun and may be seen for any sun elevation. On the contrary, due to internal reflection, the circumzenithal (resp. circumhorizontal) arc cannot be seen for sun elevations greater than 32° (lower than 58°).*

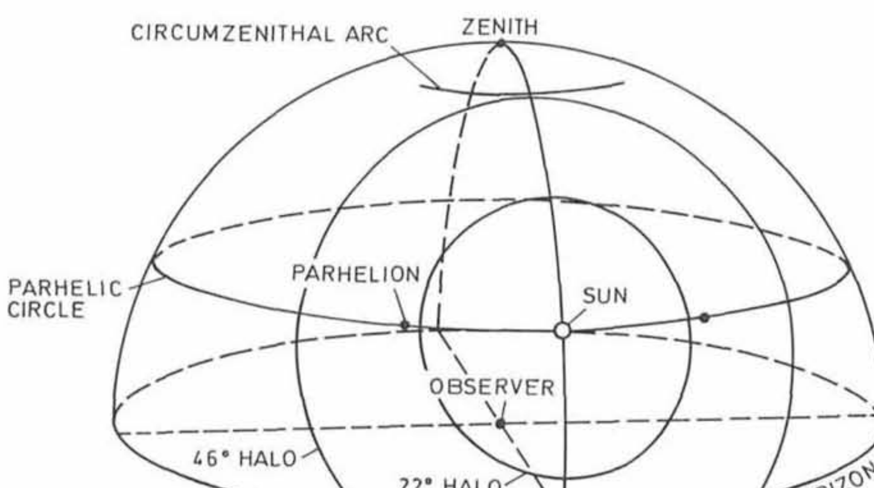

Figure 8: *A schematic perspective view of some halos discussed in this paper.*

cameras, it is clear that very interesting effects could be recorded. For example, halos of radii different from 22° and 46°, or those occurring 180° away from the sun are not yet clearly understood because of a lack of good photographic records. Photometry and polarization measurements are even scarcer. Halo observations could be a nice goal for astronomers lucky enough to get cloudy weather!

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