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SHORT AND SWEET

Coronal streamers revealed during solar eclipses: Seeing is not believing, and pictures can lie

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Abstract. For those fortunate enough to have personally witnessed and photographed the visible corona surrounding the Sun during a solar eclipse, pictures are usually a let down for not living up to the visual view. After 150 years of investigating the corona, we understand it more fully and now know this difference to be real. The difference stems from our inability to either see or image the true distribution of simultaneous brightness because of its large dynamic range (eg, Rodriguez, Woods, 2008 *Digital Image Processing*, Upper Saddle River: Pearson Prentice Hall). Brightness in the corona is unprecedented, as it falls by three orders of magnitude over a distance of only one solar radius from the Sun.

Keywords: solar eclipses, coronal streamers, image artefact, optical illusion.

Scientific investigation of the corona during solar eclipses can be separated into three roughly half-century periods over the past 150 years. During the first period spanning the latter half of the 19th century, naked eye observations were only occasionally supplemented by photography. The former were carefully reported in written accounts and recorded in drawings and engravings that depended on the skills of astronomers, artists, and engravers, as well as those who made and produced the pictures. Figure 1 shows a drawing of the eclipse of July 29, 1878 (Ranyard 1881). The striking feature of these pictures is the dominant narrowing large-scale structures now known as coronal streamers (Koutchmy and Lifshits 1990).

With its considerable progress, photography took over during the first half of the 20th century, the second period of coronal study. Improved images showed an approximately globular corona extending farther from the Sun, but without monolithic streamers [see, eg, images in Menzel (1959)]. Figure 2a is typical. Images and quantitative data are two representations of the same observation, and relating the two is essential for understanding the images. Photometric studies showed that the shape is not exactly circular, because the radial gradient of brightness is shallower in the equatorial region than it is in the polar regions (see, eg, Billings 1966).

When O'Brien et al (1939) constructed isophotes for the June 8, 1937, eclipse, they reported: "The contours are nearly circular and differ greatly from the visual appearance of streamers in the corona. It is shown that the corona has nearly spherical symmetry and that the streamers are only slight, though abrupt, transitions in brightness superimposed on the main luminosity. Their visual prominence is due to a well-known property of the eye." This noted deviation between isophotes and streamer is in fact a description of the streamer illusion. As with the ruler in the Muller-Lyer or arrow illusion, isophotes are quantitative measurements that characterize the physical reality of the corona. Seeing is not believing.

Radial brightness gradient filters were introduced in the 1960s to compensate for the rapid drop in brightness (see, eg, Newkirk et al 1970). Because the resulting "processed" images seemed to unveil the "hidden" monolithic coronal streamers seen by the eye, they have been the images of choice for the past 50 years (Pasachoff 2009), the third period of coronal study.

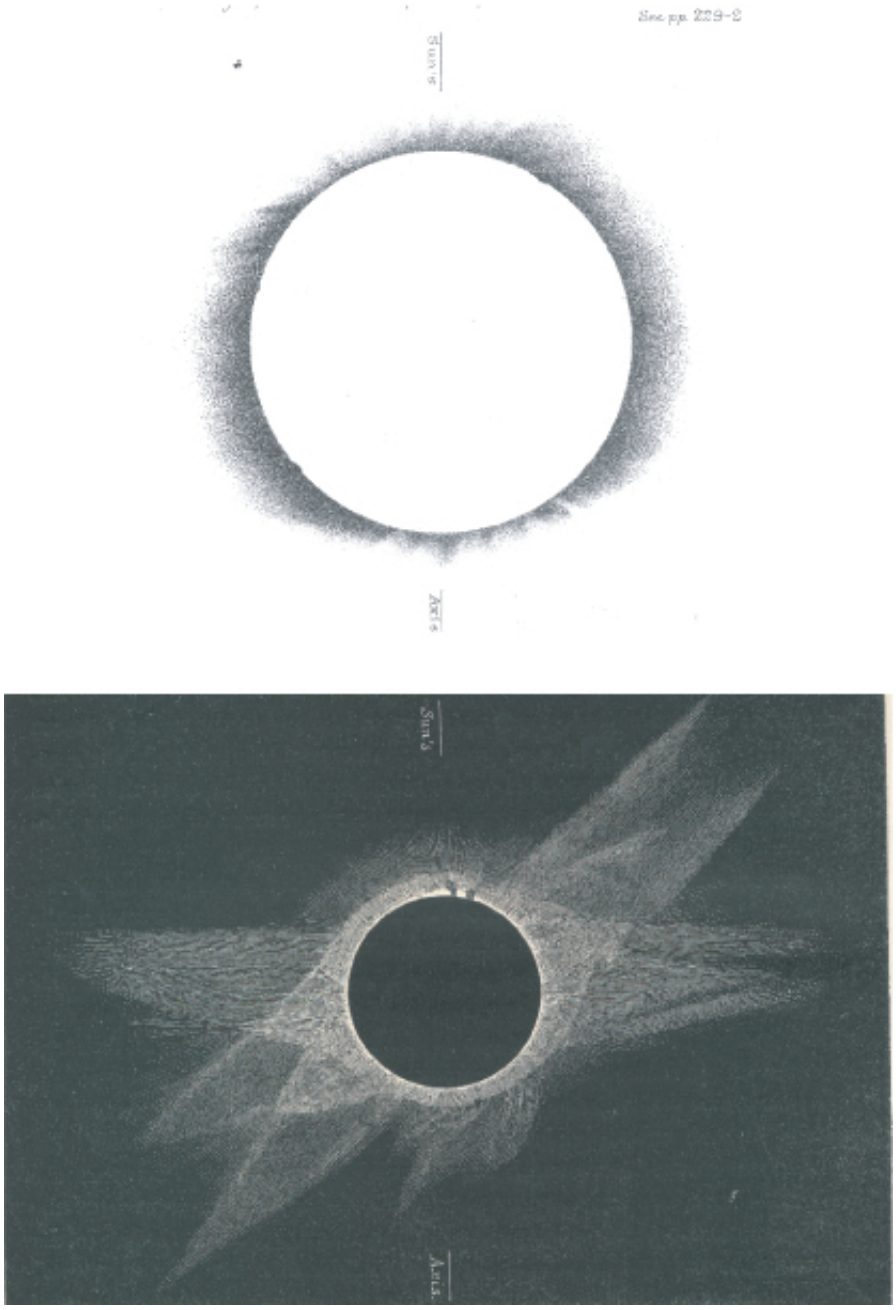

Figure 1. A photograph (top) and a woodcut of a naked-eye observation (bottom) of the corona during the solar eclipse of July 29, 1878 (from Ranyard 1881). The large-scale tapering structures in the drawing are known as coronal streamers.

Solar researchers were unfortunately unaware that a constant (independent of latitude) radial brightness gradient had been inadvertently removed. Figure 2b is a processed image of differenced brightness, not brightness (Woo and Druckmüllerová 2008). Subtraction of a gradient brings out and exaggerates the differences in the varying radial brightness gradients around the Sun, hence the jagged shape of the differenced-brightness corona. It is dark over the poles where the radial brightness gradient is steepest and deviation from the removed gradient is smallest; it is bright in the equatorial region where the radial density gradient is shallowest and deviation from the removed gradient is greatest. Artificially generated by differencing, the streamers in Figure 2b are artefacts. Pictures can lie.

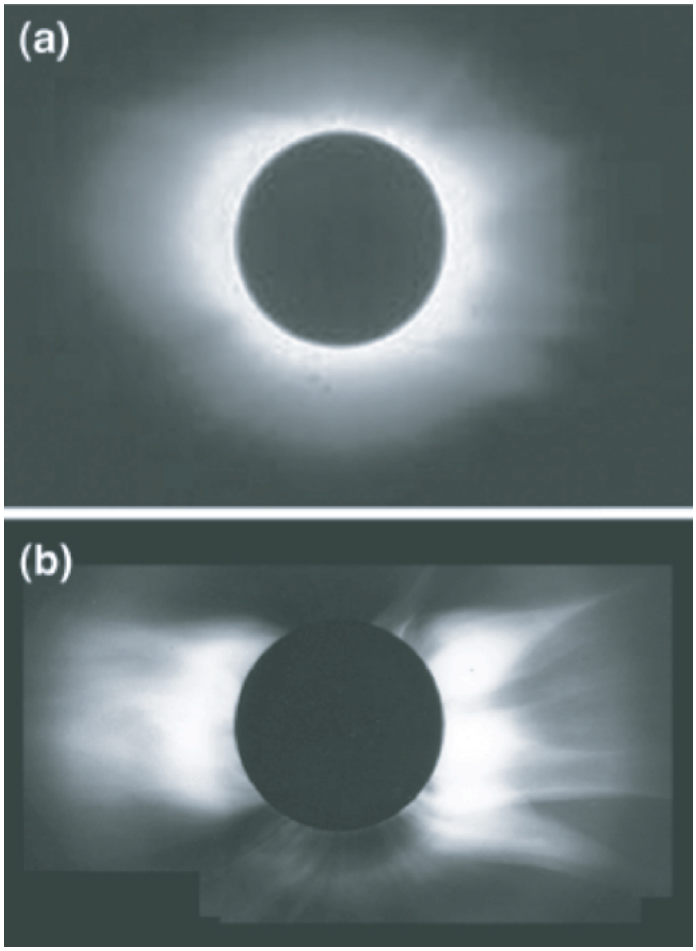

Figure 2. White-light images of the solar eclipse of June 30, 1973 (adapted from Woo 2005). (a) Taken without a radial brightness gradient filter (unprocessed). (b) Taken by a camera equipped with a radial brightness gradient filter (processed). The streamer illusion seen by eye and captured in the sketch of Figure 1 is absent in the unprocessed picture, but artificially generated as the streamer artefact in the processed picture.

Confronted by its extreme dynamic range of brightness, investigation of the corona was confused by the intersection of the physical world with peculiarities of the mind, but one informed the other. As strange phenomena that challenge our sense of reality, illusions are seldom taken seriously by science because errors are generally nuisances to be avoided rather than phenomena of interest. But, explaining how they occur reveals secrets of the brain and mind and provides insight into how perception works (Gregory 2009). By replicating the streamer illusion, the streamer artefact revealed that the brightness adaptation process by which the illusion was formed mimicked the subtraction of a constant brightness falloff.

Human vision evolved for survival, not to understand the corona. Its priority is to determine what is there. While human vision tolerates illusions because it cannot discriminate them, artefacts are the bane of scientific investigation because they spell trouble. Not realizing that coronal streamers were differenced-brightness features, solar wind scientists inferred the origin and evolution of the solar wind by interpreting them in terms of brightness; this misinterpretation has endured and misguided solar wind research for more than three decades (Woo 2010). Like the canals on Mars, it is a prejudicial illusion defined by Darius (1990, page 350, emphasis in original) as follows: "From the rationalist standpoint, the prejudicial illusion is not merely unfortunate; it is odious. The illusion, deception,

misrepresentation, is motivated, often unconsciously, by preconceptions as to what *ought* to be perceived. With the injection of a remarkably mild degree of preconception, the innocent and the inferential illusion can be impelled to rush headlong in the category of the prejudicial illusion."

The illusion of canals on Mars disappeared with the improved spatial resolution through close-up imaging of Mars by the Mariner missions, but the inability of human vision and imaging to operate over the unprecedented dynamic range of coronal brightness could not be overcome. Instead, correcting the streamer misinterpretation necessitated abandoning human vision and images as scientific tools in favor of quantitative measurements of brightness for determining the true source and evolution of the solar wind (Woo 2010).

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