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Solar Eclipse Shadow Changes: The Phenomena of Sharp and Fuzzy Shadows

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Abstract. A simple experimental model was designed to demonstrate the change in the character of shadows cast by an object during the increasingly deepening partial phases of a solar eclipse. Photographs of shadows cast by the experimental model reveal that as early as a 50 % partial phase, the Sun's light rays no longer behave as an extended source of light. The light rays become linear enough to create shadow edges that are sharp in the axis of the crescent Sun and fuzzy perpendicular to the axis of the crescent Sun.

1. The Changing Appearance of Shadows During A Solar Eclipse

Other than during a solar eclipse there is no other situation on Earth where you can witness in real time such dramatic changes in your natural ambient lighting.

On a normal clear day, the Sun is a big globe of light in the sky, sending light rays to the ground in an infinite amount of directions. This type of light is called an extended source of light. When an object is placed above the ground and casts a shadow, an extended source of light creates a complex shadow. The center of the shadow, with a sharp edge, is the umbra, the fuzzy edge of the shadow is the penumbra. The umbra is created by the direct rays of light casting a shadow. The penumbra is created by crossing rays of light; light rays from the left cross to the opposite side and rays from the right cross to the opposite side at an infinite number of angles (Fig. 1).

It's the same terminology and effect, for the Moon's shadow on the Earth during an eclipse, or sticks suspended just above the ground casting a shadow on the ground.

Many eclipse sources prior to an eclipse will discuss observing a change in the character of the shadows cast to the ground during the partial phases of a solar eclipse. Those comments will often refer to shadows "becoming sharper" but do not offer any further insight or analysis. There are pictures taken during eclipses that show shadows with sharper edges to them, but the pictures do not document crucial information about the orientation of the object casting the shadow relative to the orientation of the crescent Sun or the depth of the partial phase.

2. Experimental Model

To document the partial phase phenomena of the changes in the character of shadows during a solar eclipse, a simple experimental model was designed for the August 21, 2017 eclipse. The observing position was in southeastern Tennessee (35.51566; -84.43798) approximately 206 miles from the point of Greatest Eclipse. The observing

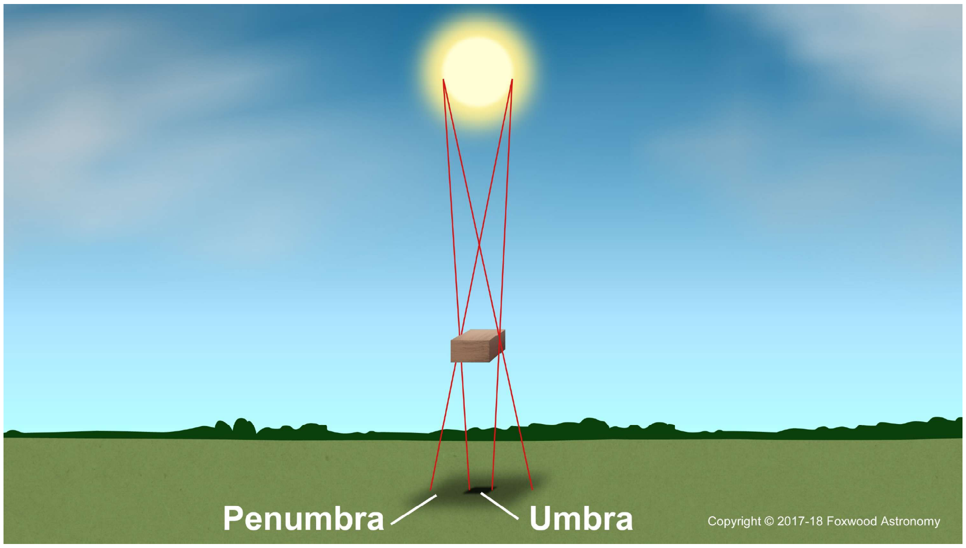

Figure 1. Objects casting a shadow from an extended source of light create a fuzzy shadow edge due to an infinite amount of crossing rays of light.

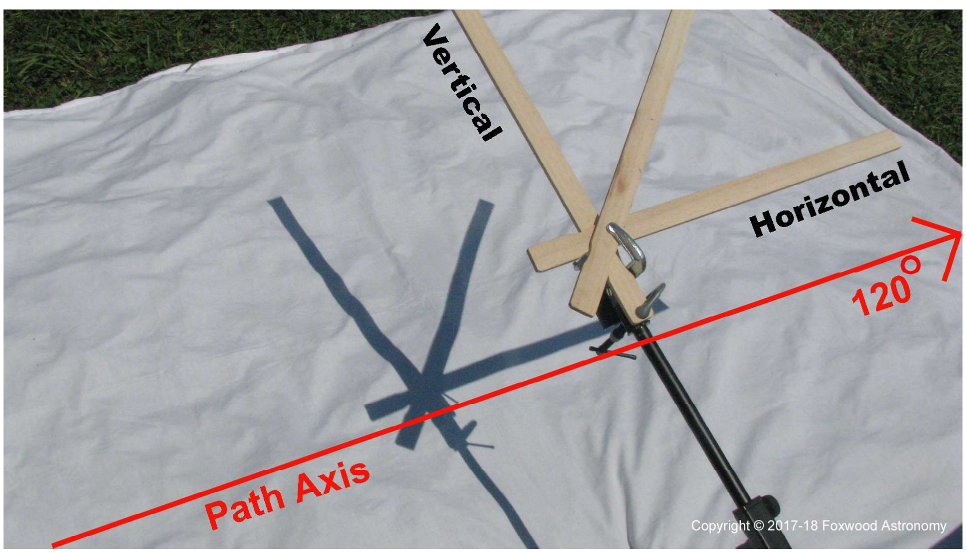

Figure 2. The model has a horizontal and vertical stick mounted perpendicular to each other. It is crucial that the horizontal stick is in line with the axis of the path of the umbra.

position was optimal for this experiment because the high Sun altitude of 63 degrees allowed the model to cast shadows directly to the ground with the minimal introduction of complex angles. Additionally, in the region of Greatest Eclipse, the axis of the path of the umbra has the long axis of the crescent phases of the Sun perpendicular to the axis of the path. This relationship was crucial for properly orienting the model to document results.

The model consisted of three sticks mounted on a stand to cast shadows on a white sheet laid on the ground. Two sticks were mounted perpendicular to each other. A third stick was mounted at a position of 45 degrees as a control. On eclipse day the positioning of the model was crucial for the design of the experiment. The horizontal stick was placed in line with the axis of the path of the umbra which was a compass heading of 300/120 degrees for the observing position. Aligning the horizontal stick along the path axis orients the vertical stick with the long axis of the crescent phases as they progress for this observing position (see Fig. 2).

When the Sun is a full globe in the sky, it is an extended source of light and infinite angles of light rays reach the vertical and the horizontal sticks creating an umbra and penumbra for both and therefore both sticks create shadows that should look fuzzy (Fig. 3).

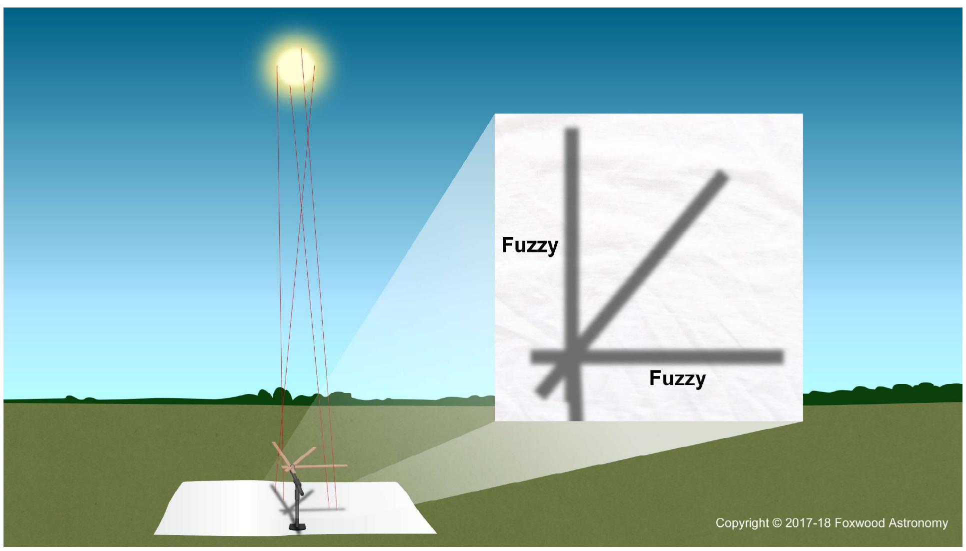

Figure 3. The Sun as an extended source of light creates fuzzy shadows from both sticks. Light rays arrive at an infinite number of angles.

When the Sun becomes a crescent the light is more linear. The long side of the vertical stick will be in line with the crescent and the linear light rays. The long side of the vertical stick creates a more direct shadow and less crossing shadows so a sharp shadow should be created (as shown in Fig. 4).

The model positions the long side of the horizontal stick perpendicular to the orientation of the long axis of the crescent. The horizontal stick is still subjected to variable angles of light rays from the upper and lower poles of the crescent and it continues to create shadows with direct and crossing rays of light. So the horizontal stick should continue to create a fuzzy shadow (Fig. 5).

3. Results

To document the effect of an extended source of light, images of the shadows created by the model were taken 6 minutes after 1st contact. To document the effect of a linear

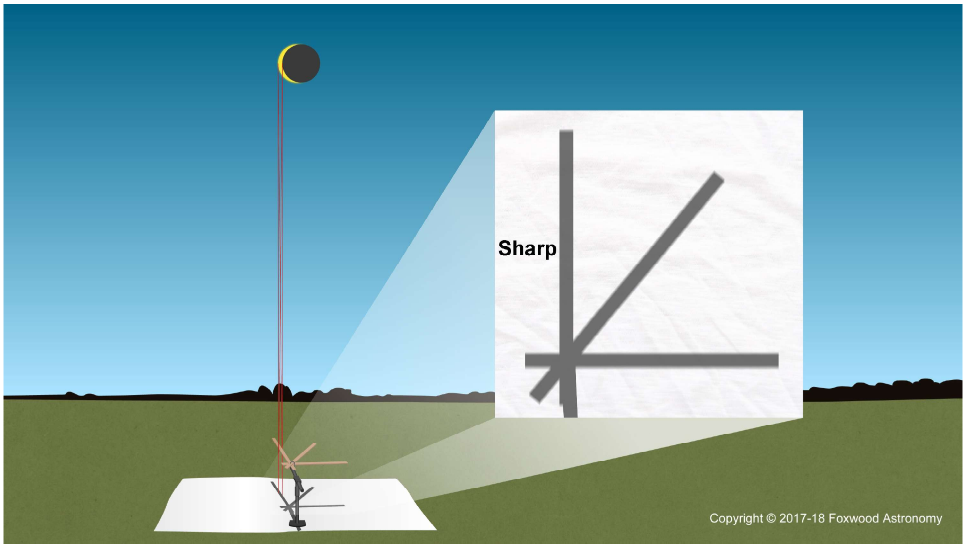

Figure 4. The long side of the vertical stick is oriented in line with the long axis of the crescent phase so the long axis of the vertical stick casts a sharp shadow.

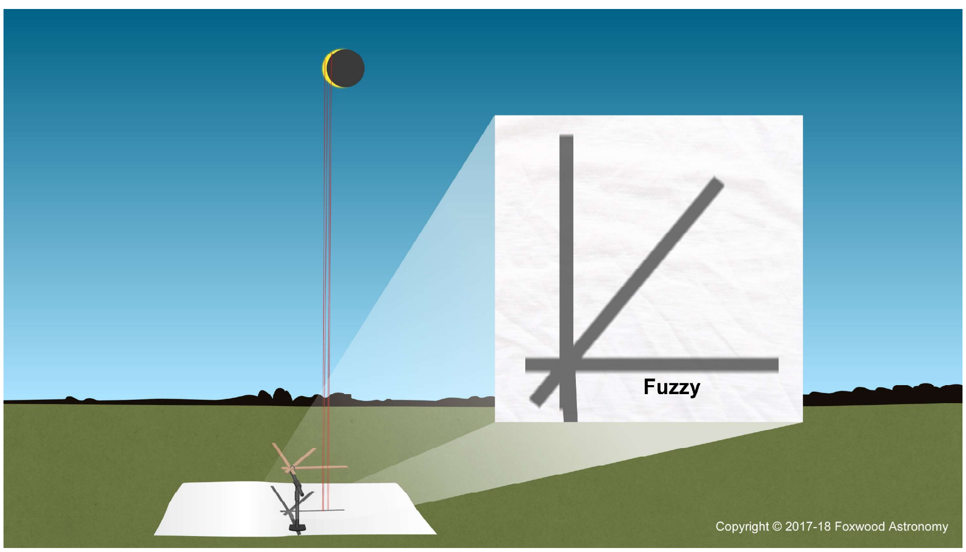

Figure 5. The long side of the horizontal stick is perpendicular to the long axis of the crescent phase so the long axis of the horizontal stick casts a fuzzy shadow.

source of light, images of the shadows created by the model were taken 47 minutes after 1st contact which was approximately a 50% crescent.

This eclipse was the initial use of this model. Since eclipse lighting changes cannot be simulated, the behavior of the model could not be tested in advance so everything that occurred on eclipse day was new data. It was understood that the simple design and field set up of the model for its initial use would introduce some errors and those will be discussed later.

The extended source images taken just after 1st contact are difficult to analyze. The umbra and penumbra effects, which create a shadow with a fuzzy edge, on both the horizontal and vertical sticks seemed to be present and relatively similar at this point (see Fig. 6). But since this was the first use of this model and this is the baseline photograph, conclusions about the lighting and the shadows being cast could not be made.

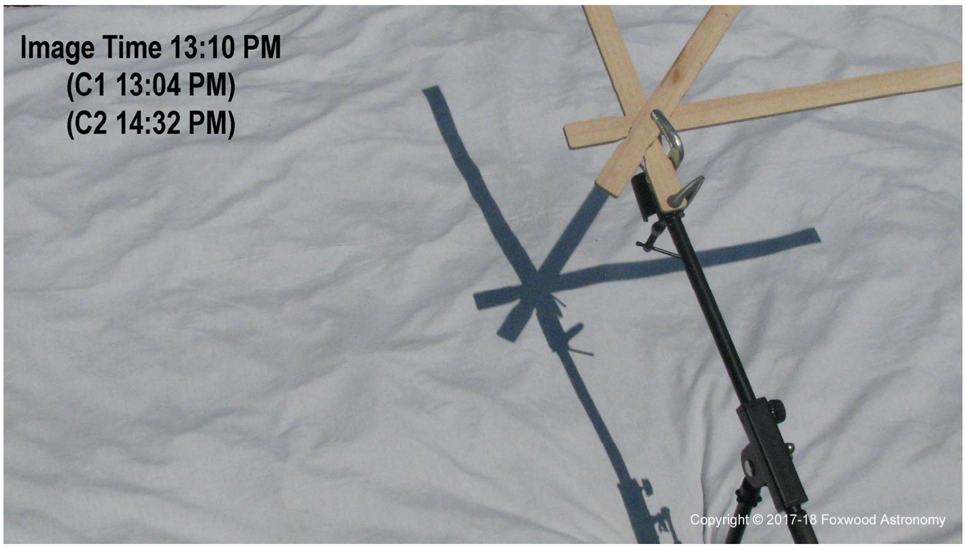

Figure 6. The initial image documenting the shadows from the model was taken 6 minutes after 1st contact. It is difficult to analyze the validity of the model at this point.

However, the images taken at a 50% crescent, 47 minutes into the eclipse, do begin to document changes in the character of shadows. At this point in the partial phase of the eclipse, the long side of the vertical stick began to cast a shadow that was sharper (Fig. 7). This is due to the light rays being more linear relative to the long side of the vertical stick since this side is oriented in line with the crescent Sun. The long side of the horizontal stick continued to cast a shadow that was fuzzy. This is due to the light rays continuing to cross the long side of the horizontal stick at infinite angles since the horizontal stick is oriented perpendicular to the long axis of the crescent Sun.

The difference in the character of the shadows becomes more apparent when looking at an expanded view of the shadows at the center region of the model. The vertical stick which is in line with the orientation of the crescent phase is casting a shadow with a sharper edge. The horizontal stick which is perpendicular to the orientation of the crescent phase is casting a shadow with a fuzzy edge (Fig. 8).

The shadow phenomena is further demonstrated by recognizing that the effect is reproduced by the parallel edges of both sticks. The long edge of the vertical stick and the short edge of the horizontal stick both create a sharp shadow because both of these edges are in line with the orientation of the crescent phase. The long edge of the horizontal stick and the short edge of the vertical stick both create a fuzzy shadow because both of these edges are perpendicular to the orientation of the crescent phase (Fig. 9).

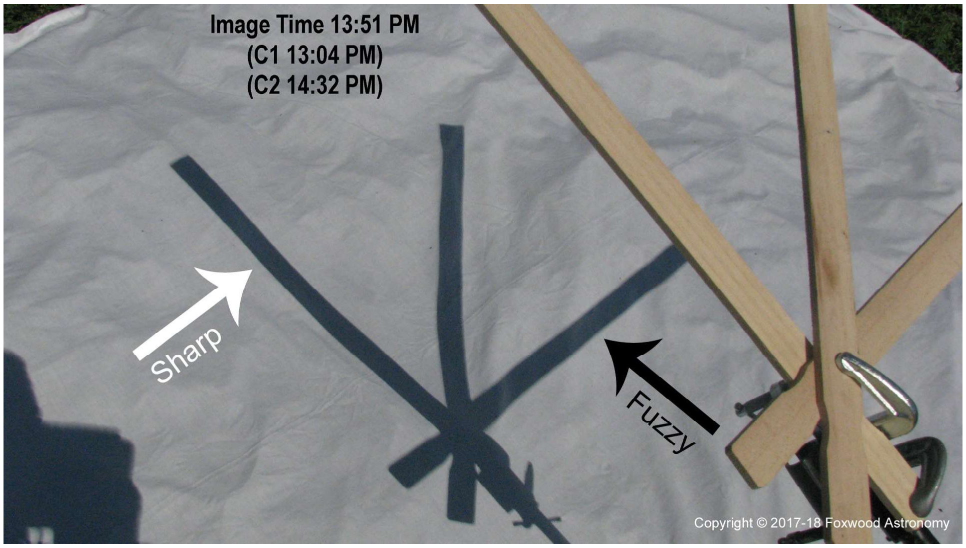

Figure 7. At 47 minutes after 1st contact the character of the shadows cast by the long side of the two sticks begins to change. The vertical stick shadow begins to get sharper and the horizontal stick shadow stays fuzzy.

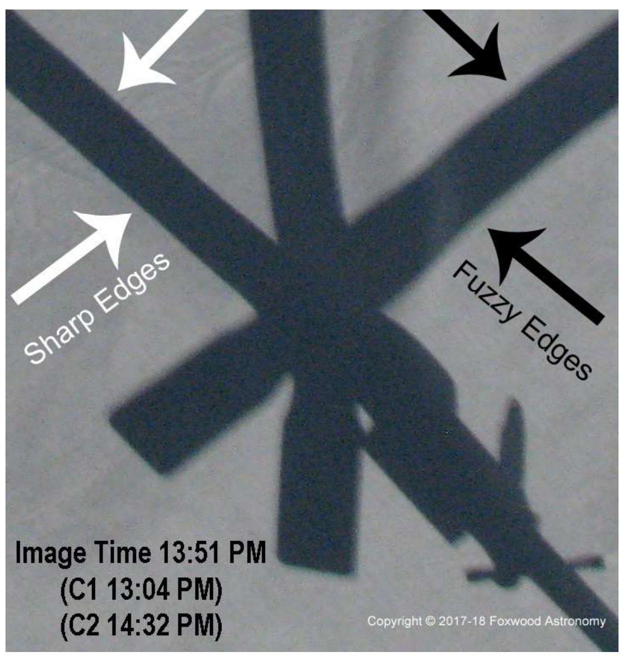

Figure 8. An expanded view reveals the difference in the shadows cast by the two sticks at a 50% crescent phase.

After the eclipse to further validate the model it was tested in controlled conditions using two different shaped fluorescent light bulbs. A round light bulb was used to represent the full globe of the Sun and an extended source of light. A long narrow bulb was

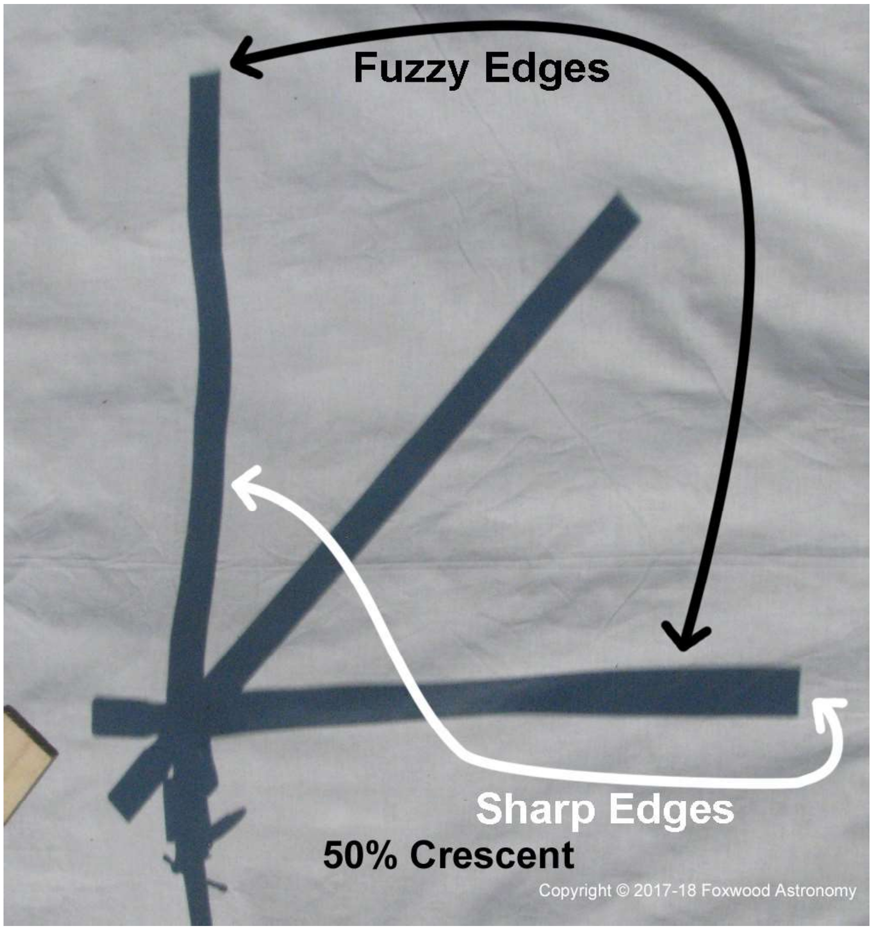

Figure 9. Parallel edges of both of the sticks cast the same type of shadow. Edges in line with the crescent phase are sharp. Edges perpendicular to the crescent phase are fuzzy.

used to represent the crescent Sun and a linear source of light. Each bulb was suspended over the model to create a shadow. The sticks were in the same plane as the white background on the floor. The sharp and fuzzy shadow phenomena is demonstrated and the validity of the model is confirmed (Fig. 10).

4. Discussion

During the August 21, 2017 total solar eclipse, an experiment was performed to distinguish and define two variables that may affect the changing character of shadows during an eclipse. 1. The lighting from the Sun changes from an extended source of light to a more linear source of light. 2. The orientation of the structure casting the shadow and its relationship to the orientation of the long axis of the crescent determines if its shadow will have a sharp edge or a fuzzy edge. The results of the experiment helped

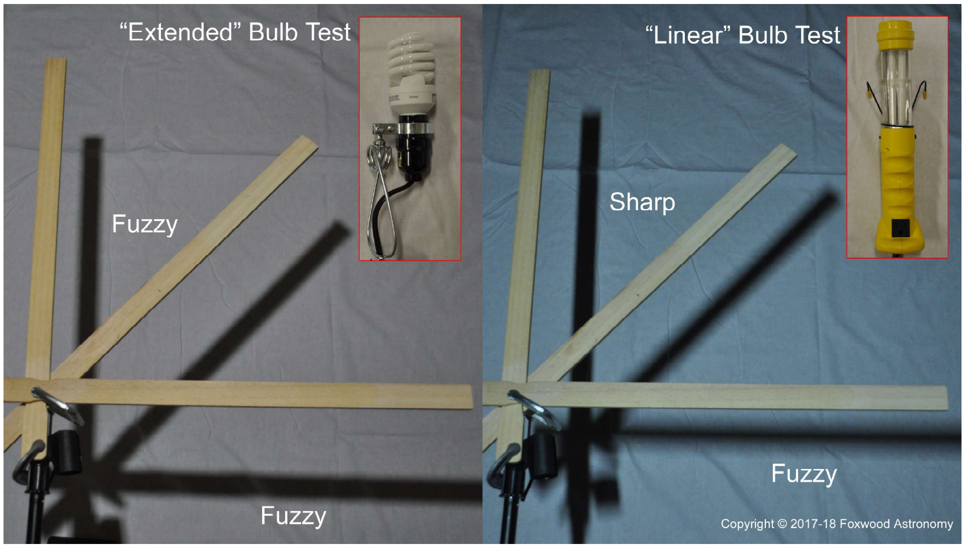

Figure 10. Test photographs using two different shaped fluorescent bulbs confirms the effect of extended versus linear sources of light and the resulting sharp and fuzzy shadows cast by the model.

identify how these two variables are related to the phenomena of seeing sharp and fuzzy shadows during the partial phases of an eclipse.

The August 21, 2017 eclipse was optimal for the experimental model because a large portion of the path was accessible around the point of Greatest Eclipse and the Sun altitude was high. At this eclipse configuration, the crescent phases are oriented perpendicular to the axis of the path of the umbra which is crucial for the model to work. Not all eclipses or eclipse observing positions will work for this experimental model as described.

The experimental model proved to be valid despite some limitations recognized during its use at an eclipse for the first time. Due to the author being involved with many other responsibilities documenting the eclipse, photographs of the shadows were only obtained just after 1st contact and midway between 1st contact and 2nd contact. The photographs of the shadows were taken with a hand-held camera and were not taken with exactly the same alignment. This is due to the fact that positioning one's self in perfect alignment with the model to take the photograph, produces a large obscuring shadow from the body of the person trying to take the photograph. Even though this eclipse had a high Sun altitude of 63 degrees and the sticks on the stand were angled with respect to the ground to create the best appearing shadow, projecting onto the ground introduced angles which may affect the quality and character of the shadows that were cast. A fabric sheet has texture which affects the quality of the photographs and it is difficult to get fabric pulled taut enough to prevent wrinkles.

When using this model during future eclipses improvements will be made to the set-up to obtain better data. A small digital camera will be fixed in the same position over the model and set in a time-lapse mode to take images throughout the duration of C1 to C2. The white background will be angled to be perpendicular to the Sun when considering its attitude and azimuth and the observing position. The stick model will be set to be in the same plane as the background. The white background will be a material with a smoother surface. The stick material will be as thin as possible to decrease edge effects of the shadows it casts.

More information may be found at `http://www.solareclipsetimer.com/`.

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