THE MARRIAGE OF ASTRONOMY AND CULTURE: THEORY AND METHOD IN THE STUDY OF CULTURAL ASTRONOMY

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Archaeoastronomy and Cultural Astronomy as Scientific Disciplines: Falsifiability and Photo Documentation

J. McKim Malville and John L. Ninnemann

Abstract: Archaeoastronomy is a discipline born at the intersection of cultural anthropology and the science of astronomy. As such, practitioners apply a variety of approaches. It is agreed, however, that casual naked-eye observation is not enough to convincingly assert the significance of prehistoric structures, alignments, and symbols. Although they can be equally creative, science differs from literary fiction in its strong preference for hypotheses that are testable and falsifiable by reproducible evidence. Digital photography is one of several tools in the field that bridges the gap between observation, essential documentation, and a search for meaning. A digital file yields both an archival image and unalterable EXIF time/date metadata. We present examples of the utility of digital photography in our studies of archaeoastronomy in the southwestern United States featuring Chimney Rock Pueblo, Yucca House Pueblo, Yellow Jacket Pueblo, Cliff Palace at Mesa Verde National Park, and Fajada Butte in Chaco Canyon.

Introduction

This paper addresses the necessity of including falsifiability in developing theories in archaeoastronomy and considers the usefulness of photography as one of several possible approaches for testing hypotheses. In our studies of the archaeoastronomy of the American Southwest, we have found photographic documentation to be a useful technique for testing predictions based upon field measurements. This paper discusses the importance of testable hypotheses and falsifiability in science, in general, and in archaeoastronomy, in particular. We consider the Russian proverb, 'trust but verify' (*Doveryai, no proveryai*) to be valuable advice.[1]

[1] S. Massie, *Trust but Verify: Regan, Russia, and Me: A Personal Memoir.* (Maine: Authors Publishing, 2013).

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Reproducibility of results is a fundamental feature of science and should be an essential element of the methodology of archaeoastronomy.[2]

In addition to the imperative of falsifiability of hypotheses in archaeoastronomy, cultural context and holistic perspective have become increasingly important in understanding the meaning of the sky for the ancient peoples. Whenever dealing with possible astronomical alignments, photography can assist in documenting the archaeological context as well as providing a broad view of the geographic setting. Unlike laboratory research, which may primarily involve the acquisition of data points, the phenomenon in archaeoastronomy is often so multivalent and visually complex that its essence needs to be documented through photography. A research programme that yields only a number such as the declination of the Sun or Moon is probably an anachronism in today's archaeoastronomy with its emphasis on emic approaches, involving context, indigenous meaning, and the implications of human agency.

We note that photography is but one (albeit a very powerful one) of a number of approaches that can lead to the falsification of a hypothesis. A further benefit of photographic documentation of the actual predicted event is to experience the phenomenon *in situ*, giving the researcher additional interpretative power by sharing the experience. Photography of the back sight also provides important documentation as well as possibly revealing light and shadow effects. Examples of this methodology as applied in the American Southwest are given in detail.

Falsifiability of a Scientific Hypothesis

> *No amount of experimentation can ever prove me right; a single experiment can prove me wrong.* —Albert Einstein[3]

> *The criterion of the scientific status of a theory is its falsifiability, or refutability, or testability.* —Karl Popper[4]

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[2] I. Lakatos, 'Falsification and the Methodology of Scientific Research', in I. Lakatos and A. Musgrave, eds., *Criticism and the Growth of Knowledge* (London: Cambridge Univ. Press, 1970), pp. 91–196.

[3] Charles M. Arthur Wynn and Sidney Harris, *The Five Biggest Ideas in Science* (New York: John Wiley and Sons, 1997), p. 107.

[4] Karl Popper, *Conjectures and Refutations: The Growth of Scientific Knowledge,* (New York: Routledge and Kegan Paul, 1963), pp.33–39.

> *The law of relativity is supposed to be true at all energies, but someday somebody may come along and say how stupid we were. We do not know where we are 'stupid' until we 'stick our neck out', and so the whole idea is to put our neck out.* —Richard Feynman[5]

Scientific ideas can never be proven true; they can only be falsified. A basic feature of the scientific enterprise is the willingness to test ones hypothesis, to 'stick out ones neck' and risk having a favorite proposal rendered false. Science moves forward by falsification. A number of years ago, the physicist John Platt published a paper in *Science* titled, 'Strong Inference: Certain Methods of Scientific Thinking May Produce Much More Rapid Progress than Others'.[6] By strong inference Platt meant the systematic application of the old-fashioned method of inductive inference that was proposed by Francis Bacon (1561–1626).[7] The necessity of testing of scientific hypotheses was emphasised by Karl Popper.[8] Strong inference can be summarised as follows: devising multiple hypotheses to explain an observation, performing an experiment or observation that can falsify one or more of those hypotheses, recycling the procedure to make sequential hypotheses to gather more data about the original phenomenon. There was nothing really new about this proposal except for Platt's insistence on the systematic application of this procedure and, especially, robust falsification. Because science advances by disproof, there is no point in advancing hypotheses that are not falsifiable. Popper stresses the issue of demarcation, distinguishing the scientific from the unscientific – and makes *falsifiability* the demarcation criterion. What is unfalsifiable is classified as unscientific, and the practice of declaring an unfalsifiable theory to be scientifically true is pseudoscience. Every 'good' scientific theory contains a number of prohibitions. The more a theory forbids, the better it is. A theory, hypothesis, or proposal that is not refutable by any conceivable method is non-scientific.

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[5] R. P. Feynman, R. R. B. Leighton and M. Sands, *The Feynman Lectures on Physics* (Reading: Addison-/weslkey, 1963), pp. 38–39.

[6] John R. Platt, 'Strong Inference: Certain Methods of Scientific Thinking May Produce Much More Rapid Progress than Others', *Science* 146 (1964): pp. 347–52.

[7] F. Bacon, *The New Organon and Related Writings* (New York: Liberal Arts Press, 1960).

[8] K. R. Popper, *The Logic of Scientific Discovery* (New York: Routledge, 2002).

There are those who object to Popper's ideas about falsification.[9] Some argue that Popper was unduly influenced by the revolutionary changes in physics that were occurring in the 1920s and 1930s and that hypotheses in science today are less dominated by fundamental premises such as that of General and Special Relativity. At the Oxford VII archaeoastronomy conference in Flagstaff, Arizona, David Whitley, a philosopher of science interested in rock art suggested that the proper methodology in science today is 'Post Positivism'.[10] He commented,

> Due to an unfortunate historical quirk, however, the earlier methods advocated before World War II by well-known philosophers like Popper and Hempel became enshrined in most physical and social science departments and they continued to be taught, at least into the 1990s despite the fact that philosophy of science *per se* had moved on.[11]

A concern shared by Whitley is the possibility that laboratory measurement is value-driven and therefore experiments that appear to falsify a hypothesis are themselves flawed by the motivations of the experimenter. Whitley suggests that hypotheses should be accepted or rejected not by falsification but by 'inference of the best hypothesis' from multiple lines of evidence. He contends, 'The use of a single data set or collection technique potentially yields a result that is a predetermined outcome of the assumptions of that approach'.[12]

Philosophers of science appear to separate themselves, in general, from practising scientists in their apparent distrust of empirical data and their preference for correction rather than elimination.[13] Falsifiability seems to be too disputative for philosophers. But, scientists are often disputative in their search for flaws in accepted theories. Abandoning the criterion of falsifiability could mislead the public about the nature of science and open

[9] See for example, David S. Whitley, 'Issues in Archaeoastronomy and Rock Art', in Todd Bostwick and Bryan Bates, eds., *Viewing the Sky Through Past and Present Cultures* (Phoenix: Pueblo Grande Museum Anthropological Papers No. 15, 2006); James Blachowicz, 'There is No Scientific Method', *New York Times*, (4 July 2016); James Blachowitz, 'Elimination, Correction, and Popper's Evolutionary Epistemology', *International Studies in the Philosophy of Science* 9 (1995): pp. 5–17.
[10] Whitley, 'Issues in Archaeoastronomy'.
[11] Whitley, 'Issues in Archaeoastronomy', pp. 86–87.
[12] Whitley, 'Issues in Archaeoastronomy', p. 87.
[13] Blackowicz, 'Elimination, Correction, and Popper's Evolutionary Epistemology'.

the door for pseudoscientists to claim that their ideas are equally scientifically legitimate.

Photo Documentation Methodology in Archaeoastronomy

When dealing with horizon phenomena our methodology should consist of calibrated photographs of both the horizon event as well as the back sight, so that other investigators could fully reproduce the data. In our studies of the American Southwest, once we had predicted a horizon phenomenon by means of Sun sights using a second-of-arc theodolite, we considered that our project was not completed until we had verified the prediction by means of photographing the event at the pre-cited location and date. Because of the effect of the changing obliquity of the ecliptic, the horizon photograph should have a well-calibrated azimuth scale. In the case of the America Southwest at the latitude of Chaco Canyon, Chimney Rock, and other sites, the effect of changes of obliquity over a period of 10 centuries is close to 10 minutes of arc, one-third the diameter of the sun, and hence in most cases what one sees today is close to that seen by the Ancestral Pueblos.[14] For earlier epochs at other sites the differences in azimuth can be calculated and applied to the photograph. Thus, the photograph of the moon rising above a recumbent stone or a trilithon of Stonehenge can be similarly documented.

Almost as important as photographic documentation of the foresight, is that of the back sight. Such a record can identify its precise location and its archaeological features. Photographic documentation is reproducible, and with digital cameras it is highly trustworthy. EXIF (exchangeable image file) metadata is produced by many cameras and smart phones. Most importantly the date, time, and often the location are recorded. Any attempt at photo editing or image modification would not escape detection. Metadata provides transparency and reproducibility of the results. Below we give an example of metadata (Table 1).

[14] Per the Jet Propulsion Laboratory, the obliquity is given by
$e = 23^{o}26'21.406" - 46".8368T - .000183T^2 + .002003T^3 + \ldots$ where T is the number of Julian centuries since J2000. Astronomical Almanac, (USA: US Governmental Printing Office, B52, 2010).

DEVICE	Nikon D5300
ISO	1250
SHUTTER SPEED	1/30 sec f/8
FOCAL LENGTH	105 mm
DATE	9/27/16
TIME	7:19:09 PM
LOCATION	Chimney Rock
SIZE	22.0 MB

Table 1. EXIF METADATA (Peterson Ridge, Chimney Rock)

Archaeoastronomy of the American Southwest

This paper describes almost three decades of collaboration between Malville and Ninnemann in exploring the archaeoastronomy of the Ancestral Pueblos. Using Sun sights with a Wild T-2 second of arc theodolite, Malville made predictions, and Ninneman the expert photographer, checked up on them in the field, often in very challenging conditions. We have chosen five places to illustrate our work because of the limitations placed on figures in this publication. There are other Chacoan Great Houses that mark the solstices, most of which have been reported at SEAC conferences.[15] In our work we have also emphasized the importance of documenting back sights. We are interested in the processes by which astronomical observations were made and exactly where, when, and why an observer-designer stood. Unless archaeologically noteworthy back sights can be found, there can be no confidence that intentionality was involved. This uncertainty is particularly vexing in the case of claims that certain walls and lines of Great Houses in Chaco Canyon were

[15] J. M Malville and A. Munro, 'Houses of the Sun and the Collapse of Chacoan Culture', in Fabio Silva, Kim Malville, Tore Lomsdalen and Frank Ventura, eds., *The Materiality of the Sky, Proceedings of the 22nd Annual SEAC Conference*. (Ceredigion, Wales: Sophia Centre Press, 2016); Andrew Munro, Tony Hull, J. M. Malville, F. Joan Mathien, and Cherilynn Morrow, 'Investigation of Solstice Horizon Interactions at Chacoan Monumental Architecture', in this volume.

intentionally aligned to the solstices and lunar standstills.[16] In contrast, the north wall of the Great House at Chimney Rock is aligned with June Solstice Sunrise as viewed from a very identifiable bedrock basin. The alignment of walls to the cardinal directions, such as north-south wall of Pueblo Bonito and the alignment of its Great Kiva, is a different matter because such orientations could have been established by means of shadow casting using a *gnomon*.[17]

1. Winter solstice over Fajada Butte

Fajada Butte (Fig. 1) is the single most dramatic topographic feature of Chaco Canyon, and it may have been a spiritual magnet for early migrants or seasonal visitors. The butte was the sacred centre of the Fajada Gap community, a group of 54 small house sites which flourished in the 900s and early 1000s CE.[18] The community contains one of the earliest Great Kivas to be constructed in Chaco Canyon. The presence of a Great Kiva and evidence of careful observations of the sky at a small house community is noteworthy because it has been generally believed that Chaco's 'high' culture had developed during the period of Great House construction. Previous investigations of astronomy in Chaco Canyon had primarily focused either upon the three-slab site of Fajada Butte or upon Great Houses and Great Kivas.[19] Very little has been written about the astronomy of the small house communities that preceded the Classic Bonito phase. In 2011 it appeared to Malville that the December solstice sun might rise over Fajada Butte as viewed from the isolated Great Kiva in Marcia's Rincon, so a permit was obtained from the National Park Service to test this prediction, which was photographically confirmed by Ninnemann and G.B. Cornucopia on very cold December mornings of 2011.[20]

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[16] J. M. Malville and A. Munro, 'Cultural Identity, Continuity, and Astronomy in Chaco Canyon', *Archaeoastronomy: The Journal of Astronomy in Culture* 23 (2010): pp. 62–68.

[17] J. M. Malville, *Guide to Prehistoric Astronomy in the Southwest* (Boulder: Johnson Books, 2008), p. 56.

[18] Thomas C. Windes, *The Spadefood Toad Site: Investigations at 29SJ 629 in Marcia's Rincon and the Fajada Gap Pueblo II Community, Chaco Canyon, New Mexico*. Reports of the Chaco Center No. 12, Branch of Cultural Research, Division of Anthropology, National Park Service (Santa Fe, 1993).

[19] Malville, *Prehistoric Astronomy*.

[20] J. M. Malville, 'The Enigmas of Fajada Butte', in Gregory E. Munson, Todd W. Bostwick, and Tony Hull, eds., *Astronomy and Ceremony in the Prehistoric*

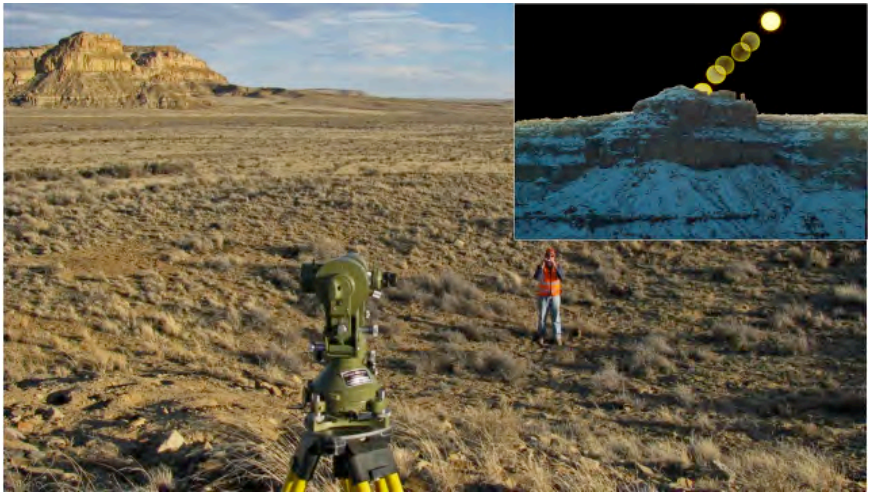

Fig. 1. Theodolite at the edge of the Great Kiva of Marcia's Rincon. The theodolite is located at the back sight above the likely antechamber of the unexcavated structure. Inset: Filtered images of December Solstice Sunrise over Fajada Butte. Both photographs by Ninnemann.

Construction of the Great Kiva in Marcia's Rincon occurred before the start of rapid growth of construction of the Great Houses sometime between 1020 and 1040 CE. During the Classic Bonito Phase, 1020–1100 CE, Chaco Canyon became the centre for periodic festivals, pilgrimages, and trade fairs, which drew in participants from outlying communities in the San Juan Basin. The regional festivals probably took place near winter solstice when the agricultural fields were fallow and the San Juan River could be easily crossed.[21]

Modest celebrations may have taken place at some of the early Great Houses and small house sites. In particular, Fajada Butte may have been an important element in early ceremonialism in Chaco Canyon. It dominates the view as one approaches the canyon from the north or south and has the

Southwest: Revisited (Albuquerque: Maxwell Museum of Anthropology, 2014), pp. 29–42.

[21] Malville, *Prehistoric Astronomy*, pp. 49–79.

quality of verticality that mythologies around the world associate with sacred mountains and the dwelling places of the gods.[22]

In Chaco Canyon, there are some 140 stairways that are associated with Pueblo occupation. Many do not seem to serve practical purposes: they are too steep and precarious to descend carrying a load. In the words of Hayes, 'Stairways are commonly associated with roads, but in many cases, rather elaborate arrangements for getting up or down a cliff were found where no other evidence of a road was found either above or below'. [23] It is possible that some of these stairways are examples of ritual ascent or descent, intended for ritual movement rather than for movement of people or trade goods into or out of the canyon.

Ritual ascents on its southwestern ramp could have taken place starting in the 900s CE. The ramp begins at the toe of the lowest talus rock slope close to a fire box with fire-reddened vertical slabs. The three sections of the ramp rise a total of 280 vertical feet and involve a mixture of masonry retaining walls, masonry stairs, carved hand and toe holds, carved stairs, and wooden platforms.[24] At the top of the ramp there is another fire reddened slab box, of which, each side is one metre.

The unexcavated Great Kiva of Marcia's Rincon (29SJ 1253) is the second largest of the 21 Great Kivas to have been built in Chaco Canyon.[25] Its diameter of 20 m is more than a standard deviation from the average of all the Great Kivas in the canyon, which is 15.8 m. The surface ceramics of the site were dominated by Red Mesa Black-on-white, which date from the 900s to early 1000s CE. The location of the Great Kiva places it within the shadow cast by Fajada Butte at sunrise on December solstice. Celebrants emerging from the Great Kiva at dawn, an experience miming their ancestors when they emerged from the worlds beneath ours, would have observed the Sun rising over the summit of Fajada Butte, and perhaps fires burning in the two fireboxes.

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[22] Ruth M. Van Dyke, *The Chaco Experience, Landscape and Ideology at the Center Place* (Santa Fe: School for Advanced Research Press, 2008); Mircea Eliade, *Patterns in Comparative Religion* (New York: World Publishing, 1963), p. 99.

[23] Alden C. Hayes, 'A Survey of Chaco Canyon Archaeology', in A.C. Hayes, David M. Brugge and W. J. Judge, eds., *Archaeological Surveys of Chaco Canyon, New Mexico* (Albuquerque: University of New Mexico Press 1981), pp. 1–68.

[24] Dabney Ford, 'Architecture on Fajada Butte', in Windes, *The Spadefoot Toad Site*.

[25] Ruth Van Dyke, 'Great Kivas in Time, Space, and Society', in Stephen Lekson, ed., *The Architecture of Chaco Canyon, New Mexico* (Salt Lake City: The University of Utah Press, 2007), pp. 93–126.

2. The Sun and Moon at Chimney Rock

In the spring of 1988, the archaeologist Frank Eddy, who had excavated Chimney Rock in the 1970s, suggested that the high mesa with its excellent horizon had the feeling of an astronomical observatory.[26] Inspection of the topographic map of the Chimney Rock mesa suggested that the sun at June solstice might rise between the twin rock towers as viewed from the Great House. However, a visit on solstice dawn falsified that hypothesis. The Sun rose some distance to the south. Finally, near the end of summer, calculations provided encouragement that the major standstill Moon might rise between the towers, and an expedition to Chimney Rock on the night of August 8, 1988, confirmed that prediction with the photograph contained in Figure 2.[27]

Over a period of several years, we located two spots for observing the June solstice sunrise. At one location, marked by the only tower on the high mesa, the Sun rises at a well-defined depression on the horizon. At the second location, marked by a basin carved into the bedrock, the June solstice Sun rises along the northern wall of the Great House.

[26] Frank Eddy, 'Archaeological Investigations at Chimney Rock Mesa 1970–1972', *Memoirs of the Colorado Archaeological Society* 1 (Boulder: US Forest Service and the University of Colorado, 1977).

[27] J. M. Malville, 'Chimney Rock and the Ontology of Skyscapes: How Astronomy, Trade, and Pilgrimage Transformed Chimney Rock, Southwestern Colorado', *Journal of Skyscape Archaeology* 1, no. 1 (2016): pp. 39–64.

Fig. 2. Major lunar standstills as viewed from the Chimney Rock Great House. Inserts: left, discovery photograph, 8 September 1988 by Malville; right, 7 January 2007 by Ninnemann.

Across the Piedra River and upward to the top of Peterson Ridge one finds the unexcavated C-shaped unit-type pueblo, 5AA8.[28] Twice a year, near the dates of equinoxes, the Sun can be seen rising between the two chimneys. This is one of nine pueblos built along the rim overlooking the Piedra River. In addition to being larger it is the only one that is rotated away from north-south to the east to face the Chimneys. Its two-storey room block overlooks an enclosed plaza containing a kiva depression and beyond to the double chimneys. There are two larger kiva depressions located to the north and south of the structure, indicating the special ceremonial role of the site.

We speculated that a similar structure might have been built on Peterson Ridge to observe June solstice sunrise. Our team searched the ridge and located the spot from which one could observe the June solstice sun beyond the Chimneys. At that location, the chimneys are in line and one only sees a single spire. Although it is a very dramatic sight, a very thorough search revealed that there are no archaeological features in this area. Without an identifiable back sight, that spot cannot be identified as a prehistoric Sun watching station. We conclude that the Chimney Rock people could not cross the Piedra River around June solstice when it was in

[28] Malville, 'Chimney Rock and the Ontology of Skyscapes', pp. 46–48.

flood and that the residents of Peterson Ridge had different priorities and were not interested in constructing a monumental building dedicated to the Sun.

3. Yellow Jacket

The Yellow Jacket Pueblo, 5MT5, lies on a 100-acre peninsula at the head of Yellow Jacket Canyon in southwestern Colorado in the Great Sage Plain. During the Pueblo III period it may have contained as many as 1200 rooms and 195 kivas.[29] Its population has been estimated at between 850 CE and 1360 CE. For a time, it was the largest settlement of the ancient Pueblo world. Its fertile neighborhood may have been the breadbasket for the ancient Mesa Verde world and beyond. Today the region is known as the 'Pinto Bean Capitol of the World'. The red soil at Yellow Jacket is fertile loess blown in from the Kayenta region around Monument Valley.[30]

Fig. 3. Sunrise over El Diente and Lizard Head. Inset. The shaped monolith of Yellow Jacket, 5MT5 is the back sight. Photography by Ninnemann

During that summer of 1986 we confirmed that the top of a standing monolith at the south end of the pueblo had been shaped into a wedge, which aligned with the first gleam of the Sun on June solstice. Also, we

[29] Malville, *Prehistoric Astronomy*, pp. 102–21.
[30] Malville, *Prehistoric Astronomy*, pp. 102–21.

discovered in the deep sagebrush along the solstice line three additional fallen monoliths, a wall, and a small shrine at the edge of the mesa. A line, established by 20 survey points was within 1/10 of a degree of our estimate of the first gleam of the sun on summer solstice of 1200 CE. We also replicated the fallen wall adjacent to the monolith and photographed the shadow of the sharp top of the monolith at solstice sunrise. That wall could have contained marks that identified the days near solstice. To the south of El Diente is a prominent spire, Lizard Head Peak (Fig. 3). It is such a dramatic spire on the horizon, it seemed possible that it may also have been incorporated in the solar ceremonialism of Yellow Jacket. The Sun rises above Lizard Head on June 5, a little more than two weeks before June solstice. As was perhaps the case in Chaco Canyon, sunrise above Lizard Head may have marked the 30-day period when the next full Moon was the full Moon closest to solstice; the occasion for celebrations and trade fairs.

4. December Solstice Sunset over Towaoc at Yucca House

Yucca House is a unexcavated Pueblo III village with as many as 600 rooms and 102 kivas. It lies in the significant area between Mesa Verde and the Sleeping Ute Mountain, the southern gateway to and from the Great Sage Plain in Southwestern Colorado. Early migrants to Chaco Canyon from the Dolores River would have had to pass through it. Some 20 miles to the north the Yellow Jacket community was probably one of the major exporters of food. Heavely laden porters could cover that distance in two days, making Yucca House a likely place to be a port of trade beteween north and south. For several centuries a community at this location probably played a role in facilitating and/or controlling north-south trade that passed through the corridor.

The Yucca House complex consists of a lower house with a great kiva and an L-shaped room block and the much larger western complex which consists of a D-shaped pueblo which surrounds the upper house, a massive two story structure (Fig. 4).[31] The rectangular upper house contains two kivas, which are larger than average, and there is no evidence of residential rooms. The height, massiveness and presence of two over-size kivas suggest a special function, similar perhaps to the Sun Temple of Mesa Verde. The Yucca House size, 440 sq metres, is smaller than the Sun Temple, but both structures contain two interior circular rooms. This structure may have been the first to have been built in the area, and it is

[31] D. Glowacki, Yucca House (5MT5006) Mapping Project Report. Crow Canyon Archaeological Centre, June 21, 2001.

possible that its location may have been established by the setting Sun over the spire of Towaoc. Immediately to the south of this building is the major spring of the area. The structures that are now visible at Yucca House may have been built up around this original structure.

A tree ring date of 1263 places the western structure in the late Pueblo III period when life was getting very difficult throughout the Ancestral Pueblo world. The climate was getting dryer and colder, and crops were failing. Famine and competition for scarce resources led to social instability and violence. The residents of the nearby pueblos of Sand Canyon (built in 1250 and abandoned sometime after 1277) and Goodman Point (built in 1260 and abandoned less than 20 years later) built their villages in defensible locations, surrounded by protective walls that included springs. Isolated homesteads, once the norm in the Northern San Juan, were abandoned as people aggregated into these more secure villages.[32]

Fig. 4. Yucca House viewed from the west. Inset: December solstice sunset over Towaoc. The star marks the place in the upper house where the photograph of sunset was taken. The dashed line leads to Towaoc. (Reconstruction of Yucca House, courtesy of Dennis Holloway). Photographs by Ninnemann.

[32] J. McKim Malville, 'Astronomy and Abandonment in the Pueblo III World', in *Goodman Point Paleohydrology*, Appendix D Wright Paleohydrological Institute, (Denver: Wright Water Engineers, 2011), pp.1–17.

5. The Sun and Moon at Cliff Palace and the Sun Temple

The previous four sites involved prominent natural horizon features. Our last case study involves the Sun Temple, a prominent artificial horizon feature visible from Cliff Palace, Mesa Verde. Located on the promontory between Cliff and Fewkes Canyons of Chapin Mesa, the Sun Temple has been one of the challenging enigmas of the Mesa Verde. There are two towers, which may have been the initial construction at the site. They may have been intended as mimicking the two natural rock towers of Chimney Rock since the major standstill moon was connected with both. These round towers were eventually surrounded by a wall with a height of 4.2 metres, according to Munson's reconstruction.[33] Most extraordinarily, the high wall apparently had no external doorways. Excavated by Fewkes during three months in the summer of 1915, the Sun Temple yielded no evidence of occupation or domestic activity. [34] Fewkes named it Sun Temple because of the eroded rock on its south-east corner that looks like rays of the Sun. With a square area of 660 sq m, the Sun Temple is the largest exclusively ceremonial structure on the Mesa Verde and, quite possibly, the largest of the Ancestral Pueblos. It is nearly twice the size of the largest of the Great Kivas.

Cliff Palace faces to the southwest and receives little sunlight during summer solstice. But for its residents, eager to receive heat from the sun on a winter afternoon, the greatest amount of sunlight and solar heating would occur during the coldest months. It is an auspicious coincidence that the Sun rock is located approximately at the place on the horizon where the sun would set at winter solstice.

At the extreme southern end of the Cliff Palace enclosure, just where the modern trail heads upward to the canyon rim, there is a smooth trapezoidal platform, at the centre of which is a pecked basin with a diameter of 8 cm and depth of 3 cm. A person standing on the platform

[33] Gregory Munson, 'Legacy Documentation: Using Historical Resources in a Cultural Astronomy Project', in Clive Ruggles, ed., *Archaeoastronomy and Ethnoastronomy:Building Bridges between Cultures* (Cambridge: Cambridge University Press, 2011), pp. 265–74.

[34] J. W Fewkes, 'A Sun Temple in the Mesa Verde National Park', *Art and Archaeology* 3 (1916): pp. 341–46.

over the basin would have seen the winter solstice Sun setting over the centre of the Sun Temple (Fig. 5).[35]

Fig. 5 Cliff Palace, Mesa Verde. Inset on left: pecked basin and December solstice sunset; inset on right: Major lunar standstill moonset. Both back sights are shown. Photographs by Ninnemann.

Close to summer solstice another astronomical ceremony may have been held in Cliff Palace to watch the setting of the full Moon at its most southern position. The full Moon is always opposite the Sun, so that when the sun is furthest north at summer solstice, the full Moon is furthest south.

During the years approaching the major standstill of the Moon, residents of Cliff Palace would have seen the full moonset at summer solstice gradually move southward toward the Sun Temple on the horizon. During two to three years around the major standstill, the full Moon at summer solstice would set over the Sun Temple as seen from Cliff Palace. At dawn near summer solstice, when life was just stirring in the cliff dwellings, the setting full Moon would have provided a spectacular sight on the opposite horizon. One of the best places for staging a public viewing of the moonset is the open area near the four-storey square tower of Cliff Palace.

[35] J. M. Malville, 'Astronomy and Social Integration Among the Anasazi', in Jack E. Smith and A. Hutchinson, eds., *Proceedings of the Anasazi Symposium*, 1991 (Mesa Verde: Mesa Verde Museum Association, 1993), pp. 155–66.

A dramatic visual reciprocity could have occurred for several years around the time of the major standstill on the mornings of the full Moon near summer solstice. A sun priest may have greeted solstice Sun rising over the dark cavern of Cliff Palace from the centre of the Sun Temple. Observers in Cliff Palace could have had a view of that celebrant on the Sun Temple silhouetted against the setting full Moon. If that person was holding a reflecting device such as a mica or pyrite mirror, the flash of sunrise would signal sunrise just as the Moon was setting. A feature of the Sun Temple, which suggests intentionality of design, is that the line tangent to its two interior circular rooms aligns approximately with the major standstill moonset and with the four-storey square tower of Cliff Palace.

Other Non-Photographic Tests

Research questions were tested in ways other than photography; such as the dating of the construction of the Great House of Chimney Rock. The preponderance of tree ring dates of the Great House and vicinity of the Great Kiva coincide with the years of major lunar standstill. Three other instances of one date each, 1011, 1018, and 1070 CE may be related to the dates of scavenged dead-fall trees and may not document intentional astronomical events. It is important to note that dates of 1011 and 1018 CE are not consistent with archaeological evidence of the first occupation of the upper mesa sometime after 1050 CE.

Year CE	Number	Location	Lunar event
1011	1	Great House	Minor lunar standstill
1018	1	Great House	Major lunar standstill
1070	1	Great House	
1076	1	Great House	Major lunar standstill
1077	10	Building 16, close to the Great Kiva	Major lunar standstill
1093	20	Great House	Major lunar standstill

Table 2. Cutting Dates at Chimney Rock[36]

The northeast face of Piedra del Sol in Chaco Canyon contains a large spiral petroglyph, which marks June solstice and June 5, establishing a period of one month centred on June solstice sunrise. The south face of Piedra del Sol contains a petroglyph that may record a coronal mass

[36] Malville, 'Chimney Rock and the Ontology of Skyscapes', p. 58.

ejection during the total solar eclipse of July 11, 1097 CE.[37] That prediction could have been falsified if the Sun were in its quiet phase at that time. Analysis of various indictors of solar activity such as aurora, naked eye sunspots, and ^{14}C abundance shows that the eclipse of 1097 CE occurred during a period of high solar activity. Two other total eclipses have occurred that also appear to have occurred during coronal mass ejections.[38]

Results

Four of the five cases we have discussed involve the conjunction of the Sun or Moon with natural rock spires. The fifth, the Sun Temple, visible as an imposing structure on the south-western horizon of the Cliff Palace, with its two towers surrounded by an impenetrable high wall may have been considered to have been uniquely powerful and sacred. When these terrestrial objects (or beings) were conjoined with the Sun and Moon, the spectacle may have been a memorable meeting of gods, a visual theophany.[39] In Table 3 we summarise our photo-documentation of predictions in the American Southwest. In a parallel and comprehensive series of investigations Munro and colleagues have demonstrated with photo-documentation that ten of the thirteen Great Houses built in the Late Bonito period (after 1100 CE) were located at places where the solstice sun rose or set at prominent features on the horizon.[40] Whatever the explicit meaning, the reoccurrence of these well documented solar and lunar events suggests that they were not due to chance or idiosyncratic individual actions. Rather, they appear to illuminate deeply ingrained patterns of behaviour and cultural norms among the Ancestral Puebloans.

[37] Malville, *Prehistoric Astronomy*, pp. 64–70.
[38] J. M. Malville, and J. Vaquero, 'Piedra del Sol: The Solar Eclipse Petroglyph in Chaco Canyon', *Mediterranean Archaeology and Archaeometry* 14, no. 3 (2014): pp. 189–96.
[39] Eliade, *Patterns in Comparative Religion*, p. 126.
[40] Munro e*t al.*, 'Investigation of Solstice Horizon Interactions at Chacoan Monumental Architecture'.

PREDICTIONS	PHOTO-DOCUMENTATION
Sunrise over Fajada Butte from the Great Kiva in Marsha's Rincon	Confirm
Moonrise between Chimney Rock spires from the Great House	Confirm
Sunrise between Chimney Rock Spires from Peterson Ridge	Confirm
June solstice sunrise between Chimney Rock Spires from Great House	False
June solstice sunrise above merged Chimney Rock spires from Peterson Ridge	False
December solstice sunrise marked on horizon from Wijiji	Confirm
December solstice sunrise from Kin Kletso	Confirm
December solstice sunset over the Sun Temple	Confirm
Major standstill moonset over Sun the Temple	Confirm
June solstice sunrise over Lizard Head from Yellow Jacket	Confirm
December solstice sunset over Towaoc from Yucca House	Confirm
June solstice sunrise at Piedra del Sol	Confirm

Table 3. Predictions and Testing of Sites by Photo-Documentation

Concluding Remarks

An anonymous reviewer of this paper commented that photographic documentation is 'icing on the cake and is used, where possible and when time permits'. The reviewer continued: 'The claims made by the author that digital photos are essential and 'gap bridging' is overstating the case'. We regret that this reviewer does not agree with our recommendation that photographic documentation should be part of standard methodology in cultural astronomy. An understanding of the cultural meaning of astronomical phenomena in any culture should be an imperative in most cases, and thick descriptions accompanied by careful photography can assist in that search for meaning.[41]

[41] J. M. Malville, 'Reading Alien Landscapes: Thick Versus Thin Descriptions in Archaeoastronomy', in F. Pimenta, N. Ribeiro, F. Silva, N. Campion, A.

We have emphasized the importance of photographic documentation of both fore sight and back sight for the purposes of reproducibility of the measurement, recordation of archaeological features, and identification of possible light and shadow phenomena. Claims of alignments of walls to astronomical events must remain problematic until convincing back sights can be identified in the archaeological record.

Notwithstanding the arguments of professional philosophers of science, we believe that most scientists agree that falsifiability is a *sina qua non* of science or, stated differently, that non-falsifiable science is an oxymoron. An important issue for scholars in archaeoastronomy and cultural astronomy who are interested in maintaining these fields as scientific, is that of falsifiability, and it can be approached very simply in the form of a question: what potential evidence (perhaps photographic) would persuade you that your hypothesis is wrong?

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