

On Inca astronomical instruments: the observatory at Inkaraqay – El Mirador (National Archaeological Park of Machu Picchu, Peru)¹

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Abstract

This article is dedicated to a special category of structures that may be called “astronomical instruments”, constructed in the Inca Empire (ca. 14-16 c. AD). As mentioned in some sources, these were intended for use by a small group of priests-astronomers. A good example is Intimachay in Machu Picchu, which was recently re-designated as an astronomical observatory, far more complex and precise than was previously believed. The discovery of Inkaraqay – El Mirador, a second structure, even more complicated than Intimachay and erected for the purpose of precise astronomical observation, confirms the importance of the knowledge of the skies in the running of the Incan Empire.

Resumen

DE LOS INSTRUMENTOS ASTRONÓMICOS DE LOS INCAS: EL OBSERVATORIO DE INKARQAY - EL MIRADOR (PARQUE ARQUEOLÓGICO NACIONAL DE MACHU PICCHU, PERÚ)

Este artículo está dedicado a una categoría especial de estructuras que podemos denominar como “instrumentos astronómicos”, construidos en tiempos del Imperio Inca (ca. siglos XIV – XVI d. de Cristo). Conforme a algunas fuentes, tales estructuras fueron diseñadas para el uso de un grupo muy limitado de personas, los sacerdotes-astrónomos. Un buen ejemplo es el Intimachay en Machu Picchu, recientemente reinterpretado como un observatorio astronómico, mucho más complejo y preciso de lo que se creía anteriormente. El descubrimiento de Inkaraqay - El Mirador, una segunda estructura, incluso más complicada que Intimachay y erigida con el fin de una observación astronómica precisa, confirma la importancia del conocimiento de los cielos en el funcionamiento del Imperio Inca.

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1. Astronomy and administration in the Inca Empire

The rapid expansion of the Inca Empire (ca. 1400-1572 AD), from a small polity in the Cuzco region to an empire running the length of the Andes, created tremendous pressure on Incan social and political institutions.

The empire's growth required an increasingly complex, hierarchical structure and the organization of an extensive ruling elite.

The astronomical know-how was very important during the state expansion, providing the Inca elites (and particularly the Inca Emperor) with an instrument to assert their right to rule through the control of rituals and by their dominant position within the state cosmology (Bauer and Dearborn 1995).

Astronomical knowledge is based primarily on practical observation of celestial phenomena, requiring some, however rudimentary, devices such as gnomon or properly planned and oriented buildings. An example of such a relatively simple solution in the area of today's Mexico is the famous "El Caracol" at Chichen Itza

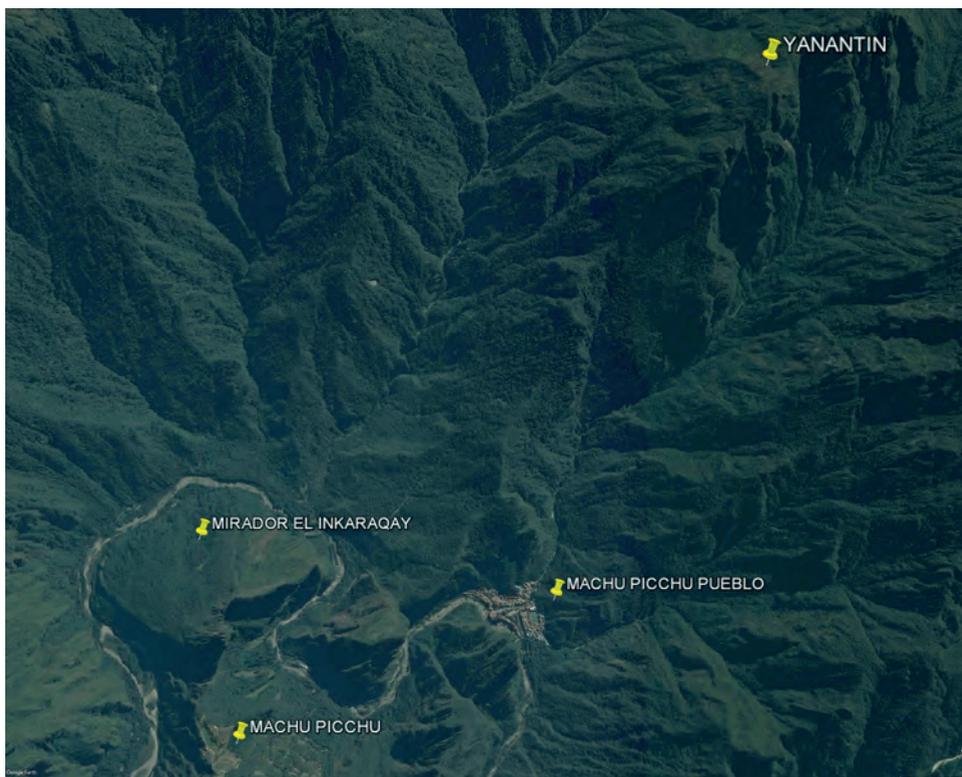


Figure 1. Satellite photo of the area of Machu Picchu, indicating the position of Inkaraqay – El Mirador and the Mountain of Yanantin (photo: Google Earth).

on the Yucatan peninsula, constructed in approx. 1000 AD (Aveni *et al.* 1975). No comparable constructions were previously known from archaeological evidence in the area of the former Inca state,² leading to speculations as to the extent of their observation techniques.

It should also be noted that when discussing devices used for tracking the movement of celestial bodies, two different categories of objects are considered:

- Those, due to religious and ceremonial reasons, aimed at an approximate orientation towards the rising or setting of the Sun (or other celestial body) at some important moment in its annual transition across the horizon. What was of importance in these cases was not so much precise astronomical observation but rather creating a visual effect for the masses of faithful gathered in large plazas in the main ceremonial centers (Aveni 1981; Ziółkowski 2015).
- Those, which may be called “astronomical instruments”, intended for use by few priests-astronomers, as mentioned in some sources.

The latter category of objects was very scarce, but Intimachay (Ziółkowski *et al.* 2013; Ziółkowski 2015) and now Inkaraqay – El Mirador (both in Machu Picchu) appear to be an example.

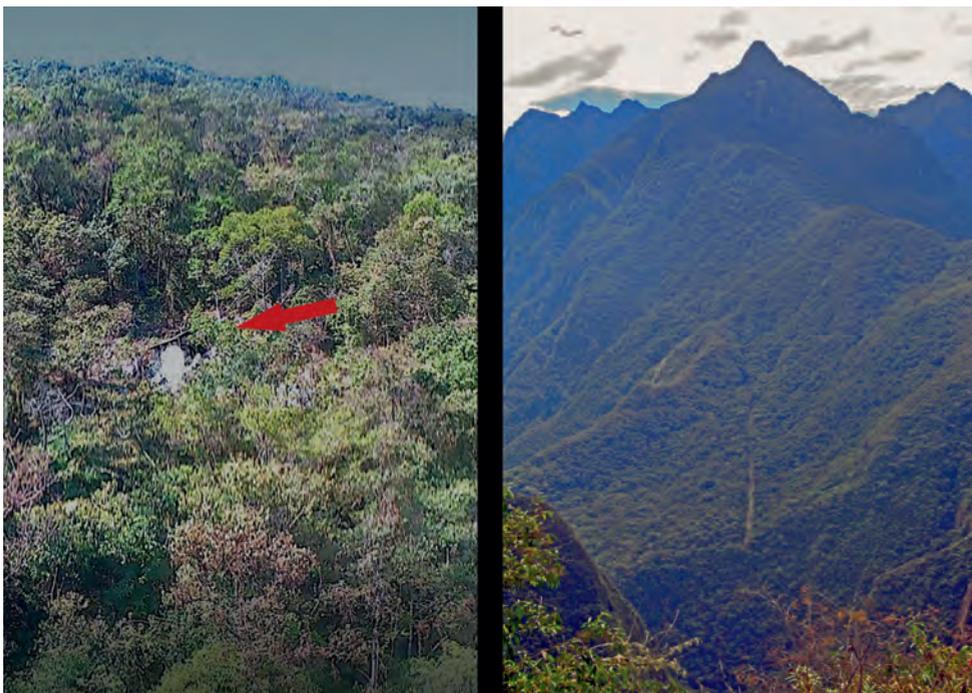


Figure 2. Aerial photo of the site - the red arrow indicating the position of Inkaraqay – El Mirador (left - photo: Bartłomiej Ćmielewski) and Yanantin summit as seen a from the Machu Picchu site (right – photo: Jacek Kościuk).

2. Description of Inkaraqay – El Mirador

Inkaraqay – El Mirador is a small structure situated on the northern slopes of Huayna Picchu (Fig. 1, 2). Architectural remains, which are still preserved on the site, consist of three parallel walls placed perpendicularly to the steep slope of the hill. The lower wall serves as a retaining wall stabilizing footings of the building situated above. At the same time, it creates a narrow (ca. 1.75 m) platform facilitating access in front of the building. The middle wall is ca. 1.25 m wide and its façade is preserved to a height of ca. 3.5 m. The carefully executed stone masonry is of a pseudo-coursed kind with slightly sunken joints. This type of stonework is characteristic for buildings of the highest importance and prestige (Fig. 9).

Although the detailed examination is still in progress, preliminary conclusions concerning the order in which particular walls were erected, can be already offered. They are based mostly on observations of vertical joints between the walls, clearly indicating construction sequence (Fig 5).

The 1st step (Fig. 7 – in red) was to build a foundation platform on the steep slope of the natural bedrock (Fig. 6). Parallely, further to the south, a retaining wall was erected on the top of carefully leveled bedrock. Probably its function was to stabilize the slope of the hill. During the 2nd building phase (Fig. 7 – in green), the main wall with niches together with its lateral extension to the north was erected. Probably at the same time another retaining wall has been added to the south. The 3rd step (Fig. 7 – in yellow) was to add facing to the foundation platform erected dur-



Figure 3. 3D Photogrammetrical model of the site as seen from the North (photos and photogrammetry by Ciechosław Patrzalek and Jacek Kościuk).



Figure 4. 3D Photogrammetrical model of the site – vertical view (photos and photogrammetry by Ciecchosław Patrzalek and Jacek Kościuk).

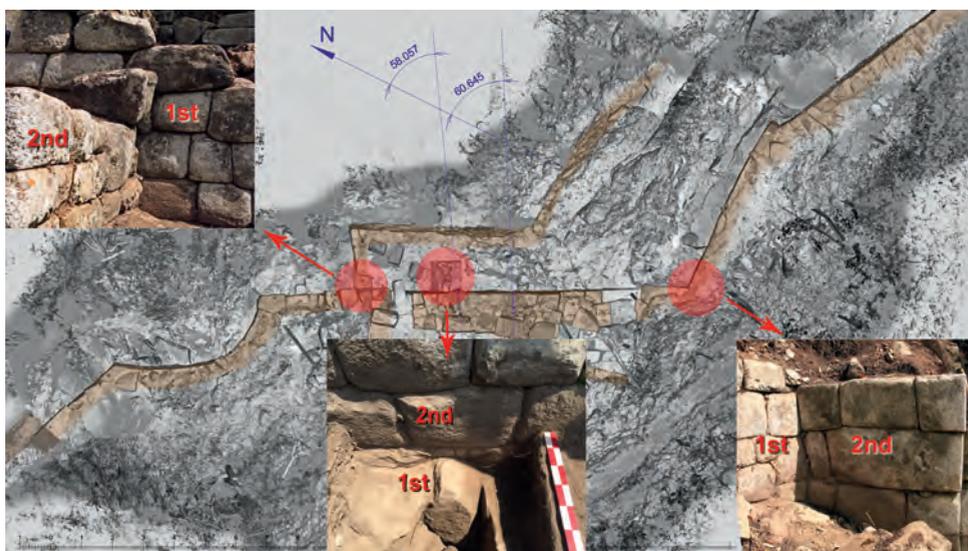


Figure 5. The plan of Inkaraqay-El Mirador and the main links between different building phases (photos and drawing by Jacek Kościuk).



Figure 6. Photogrammetrical 3D model of the small test trench built at the foot of the main wall (photos by Jose Bastante Abuhebd, photogrammetry by Jacek Kościuk).

ing the 1st phase. At roughly the same time, the back wall of the whole building has been added, as well as a further, northern continuation of the retaining wall. The limits of northern and southern extents of the retaining wall are still to be traced. During the last, 4th phase (Fig. 7 – in blue) a small retaining wall was added in order to provide a secure access to the platform in front of the main wall.

On the back of this latter wall, two sets of niches are extant. Three of them, roughly 1.6 m high, start directly above the floor of the building. They are approximately 70 cm in width. The middle niche and the most northern one are equipped with two observation openings (Fig. 8, 9).

It should be emphasized that the openings have been made in a very careful and structurally well thought out manner (Fig. 10,11). Analysis of the construction process allows for the hypothesis that the said wall was planned according to the appropriate placement and orientation of these apertures. The manner of making the observation openings is of par-

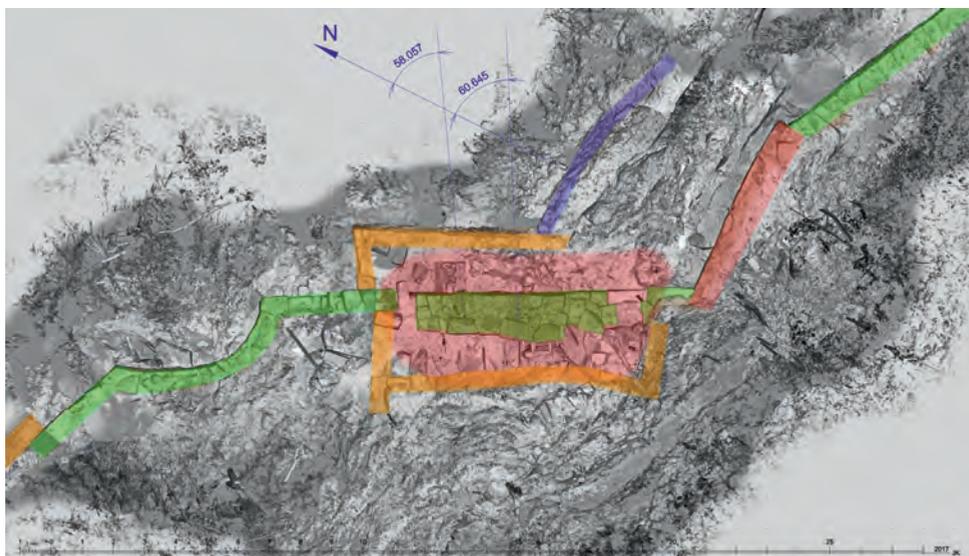


Figure 7. The main chronological phases of construction (drawing by Jacek Kościuk).

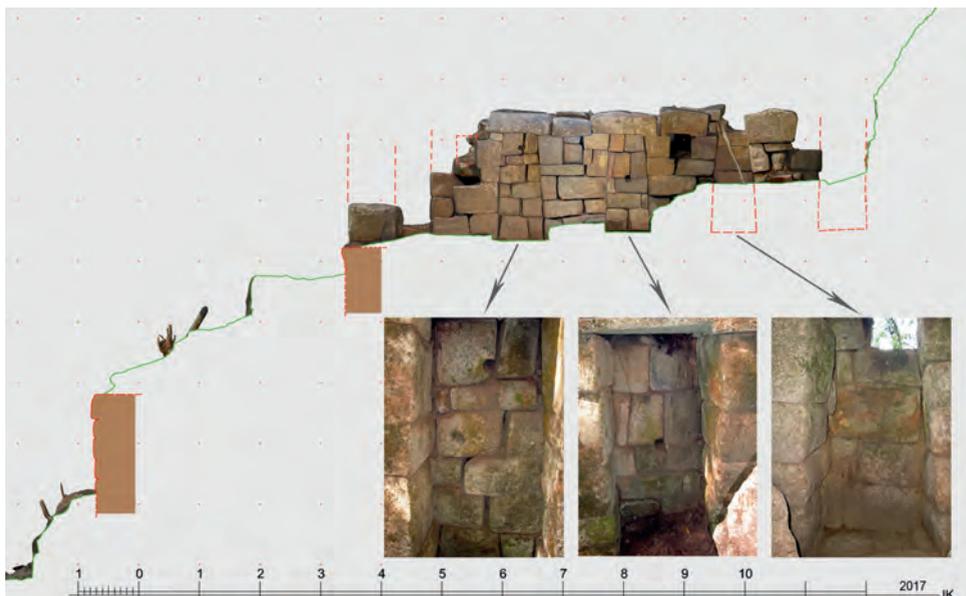


Figure 8. The back face of the main wall with 3 niches (drawing and photos by Jacek Kościuk).



Figure 9. The Inkaraqay – El Mirador façade. Arrows indicate the outlets of observation openings (photos: Mariusz Ziółkowski, stitching panorama and description: Jacek Kościuk).

ticular importance. It can be traced especially well in the case of the northern niche (Fig. 12, A-D). First, in the space designated for the opening, a stone block with a slightly sloping north face was embedded (Fig. 12 A). The orientation of thus prepared face indicated approximately the point of sunrise over the Yanantin summit during the June solstice. The next step was a correction of the north face of the block so that its plane crossed the horizon line at desired position (Fig. 12 B). In the next step, probably following the June solstice observation, a shallow canal was carved in the already prepared northern face of the block, indicating precisely the point of



Figure 10. The northern observation opening: the outlet on the façade (left – photo: Mariusz Ziółkowski) and the interior (right – photo: Jacek Kościuk).



Figure 11. The southern observation opening: the outlet on the façade (left – photo: Mariusz Ziółkowski) and the interior (right – photo: Jacek Kościuk).

sunrise over the summit (Fig. 12 C). The final step was the addition of another block with an already carved, much deeper groove (Fig. 12 D). The southern observation opening was made the same way. It seems, however, that in this case, the zenith angle was more important to the builders than the azimuth angle; the entire process was started not with the orientation of the lateral azimuth of the vertical face of the first block but on the contrary, from the zenith orientation of the top horizontal plane of the block in which the observation channel was then made (Fig. 12, A-D).

The southernmost niche has no other opening.³ Two smaller niches (ca. 30 by 50 cm) are placed between the bigger ones at a height of ca. 1.05 m above the

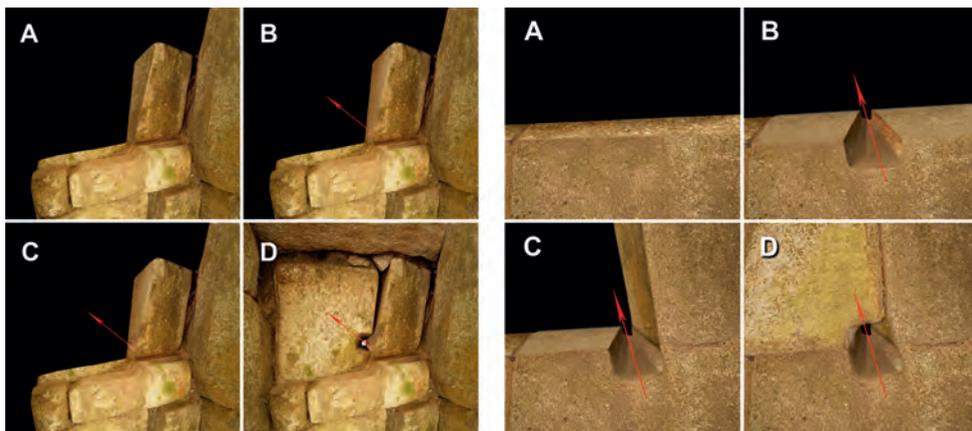


Figure 12. The reconstruction of the sequence of the northern opening construction (left) taking into account the method of determining the very precise horizontal orientation and the reconstruction of the sequence of the southern opening construction (right) where less precise vertical orientation was required (reconstruction by Jacek Kościuk). Compare with the precise description of the process in the text.

floor.⁴ There was also a third niche of this kind. Its southern edge is still preserved north of the northernmost big niche (Fig. 8).

Two openings facilitating access to the building are preserved on the southern and northern ends of the front wall. The southern one, with still preserved threshold and step, is ca. 80 cm wide. It has door recesses facing outside, typical for Inca architecture. This doorway was accessible directly from the narrow platform located in front of the building. Due to the incomplete state of preservation, the form and function of the second opening are under discussion.

Behind the wall with the niches, there is a narrow (roughly 1.5 m) corridor. Its back wall is built directly against the slope of the hill. Stone masonry is executed from rectangular stones placed in a horizontal pattern. We believe that this wall must once have been plastered, as it was common practice in the Inca architecture, especially in the case of building with prestigious, ceremonial functions. It could be of particular importance in facilitating observations of sun rays passing through the opening in the northern niche, which will be discussed further (Fig. 3, 4, 15).

3. The study

In August 2012, the personnel of the Archaeological Park of Machu Picchu carried out archaeological research at Inkaraqay. At the same time, a preliminary topographical plan of the structure was made. Between 2013 and 2017, the Peruvian-Polish research team performed the following important work (Fig. 13):

- 3D laser scanning of the entire site using Leica P40 scanner.⁵



Figure 13. Inkaragay – El Mirador site at the beginning of fieldwork in 2013 (left photo: Mariusz Ziółkowski) and the archaeo-astronomical survey (right photo: Adine Gavazzi).

- Photogrammetrical documentation consisting of nearly 4000 high-resolution images – 18 mln pixels each.
- Detailed scanning of both observational niches with handheld Artec Eva scanner.
- Drawing a detailed topographical plan and architectural cross-sections, based on the scan results and photogrammetry.
- Archaeological and architectural analysis, based on the above-mentioned documentation and a survey test-pit at the base of the main wall (Fig. 6), as well as on the interpretation of the results of the preliminary survey realized in 2012.
- Precise object orientation was then conducted, applying the method of 10 direct observations of the solar disc, using a theodolite equipped with filters. The accuracy of orientation calculated this way is ca +/- 2 MOA.

This last study allowed to determine that the orientation of the axis of the northernmost opening is aimed at ca. 21° over the horizon at ca. 58° azimuth. Corresponding readings for the middle niche (or southern) opening are ca. 19.5° and 60°. When looking through them perfectly coaxially, both cover ca. 2.5° of the horizon vertically and horizontally. However, by changing the eye position, the observer can expand the horizontal field of view from 54.5° to 59.5° in case of the northern opening and from 57.75° to 62.25° for the southern one (in the middle niche).

In both cases, the horizon line (and the related visible part of the sky) is determined by the summit and slopes of the Yanantin mountain (Fig. 2 right, 13).

- A three-dimensional model of the structure was made on the basis of photogrammetry (Fig. 3,4), used for a computer analysis of its possible astronomical functions. Stellarium 0.12.4 and Cartes du Ciel (Sky Charts) 3.8 software were used for the simulation.

4. The function of the observation openings

As mentioned, both openings were very precisely made and oriented; the architectural analysis shows that they could not have performed any function other than observational. Observation *in situ* carried out on June 20-21, 2014, showed that, in accordance with the results of model analysis, Sunrise is visible

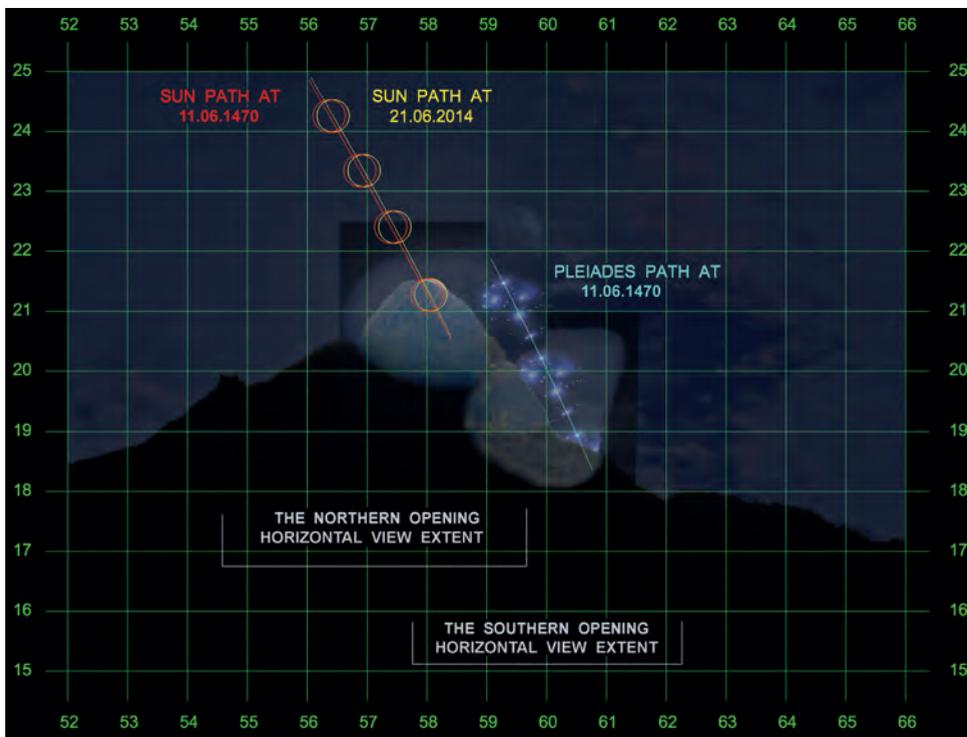


Figure 14. Reconstruction of the conditions for observing the sky through both openings showing view fields alongside their main axes. The lower scales (in grey) show the maximum range of visibility from each opening when changing the position of the observer's eye. The yellow path represents Sun positions during June Solstice Sunrise observed (and photographed) on 21.06.2014. JSSR in 1470 AD, the approximate date of the construction of the building, is marked as the red path. The reconstructed positions of the Pleiades in 1470 AD, as seen through the southern opening, are represented in blue (reconstruction by Mariusz Ziółkowski and Jacek Kościuk using Cartes du Ciel 3.08 and Stellarium 0.16.0 software).

through the north opening directly above the Yanantin summit during the June solstice (Fig. 14). The accuracy of the model analysis was thus confirmed, which allowed it to be used to reconstruct the sky at the end of the fifteenth century, the approximate period of the erection of the structure (for the purposes of analysis the year 1470 AD was arbitrarily chosen)⁶. Part of the findings obtained in this manner is shown on Figure 14. The main results of this analysis, for reason of precision, are discussed in points:

1) It was already mentioned, that the most spectacular phenomenon is observing the Sunrise right over the Yanantin summit during the June solstice. This phenomenon is visible through both openings but centered in the northern one (Fig. 14 left). It should be noted, however, that observation with the naked eye is possible only in the initial phase of the phenomenon; once the entire solar disk is above the horizon, its glow is too blinding. One can hypothesize that in this particular case, this opening was used not for horizontal but gnomonic observation, following a ray of sunlight falling on the back wall of the structure (Fig. 15). We can

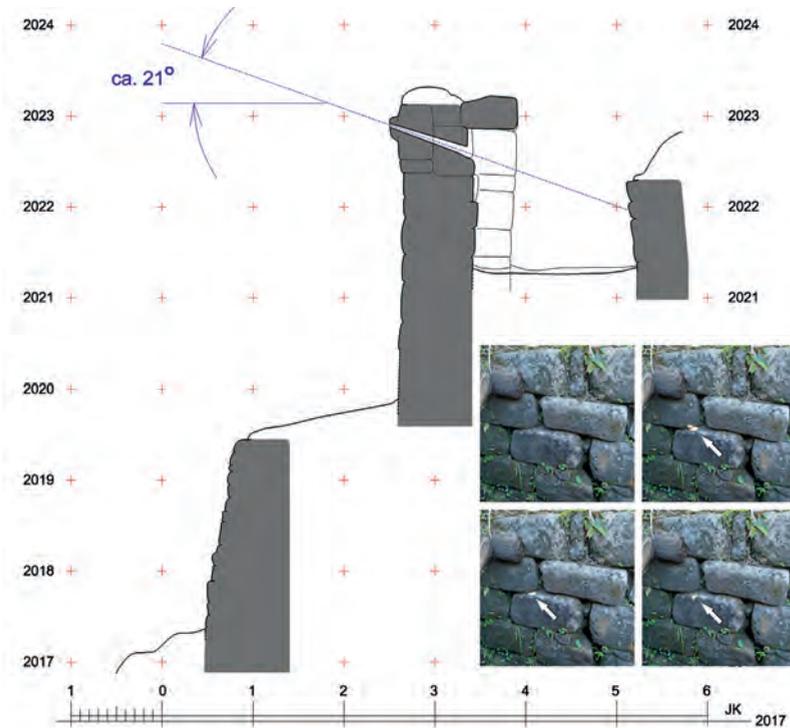


Figure 15. Vertical cross-section of the northern opening, indicating how the sunrays fall on the back wall of the chamber at June Solstice Sunrise (left - drawing by Jacek Kościuk). Photographs showing the movement of sunlight on the back wall of the chamber on June 21st, 2014 (right – photos: Jacek Kościuk). Originally, the wall was most likely covered with plaster, which greatly facilitated gnomonic observation.

assume, that if there was plaster on it (which, as mentioned earlier, was the norm in the Inca buildings of this class). This observation could be further aided by specific signs made in it. The existence of similar systems of gnomonic observation is mentioned in some historical sources, which we will discuss later on.

2) The path of the Pleiades during their heliacal rising could also be observed through both openings, but mainly through the southern one. This phenomenon was particularly spectacular, as at the end of 15 c. AD, the Pleiades seemed to be “climbing” in their transition along the southern slope of the Yanantin mountain (Fig. 14 right, 16).

It should be noted at this point, that observation of the heliacal rising of the Pleiades was of great significance to the pre-Hispanic Andean community, including the Incas. The appearance of this group of stars was used to predict the harvest in the growing season approaching; this practice has been described in a number of

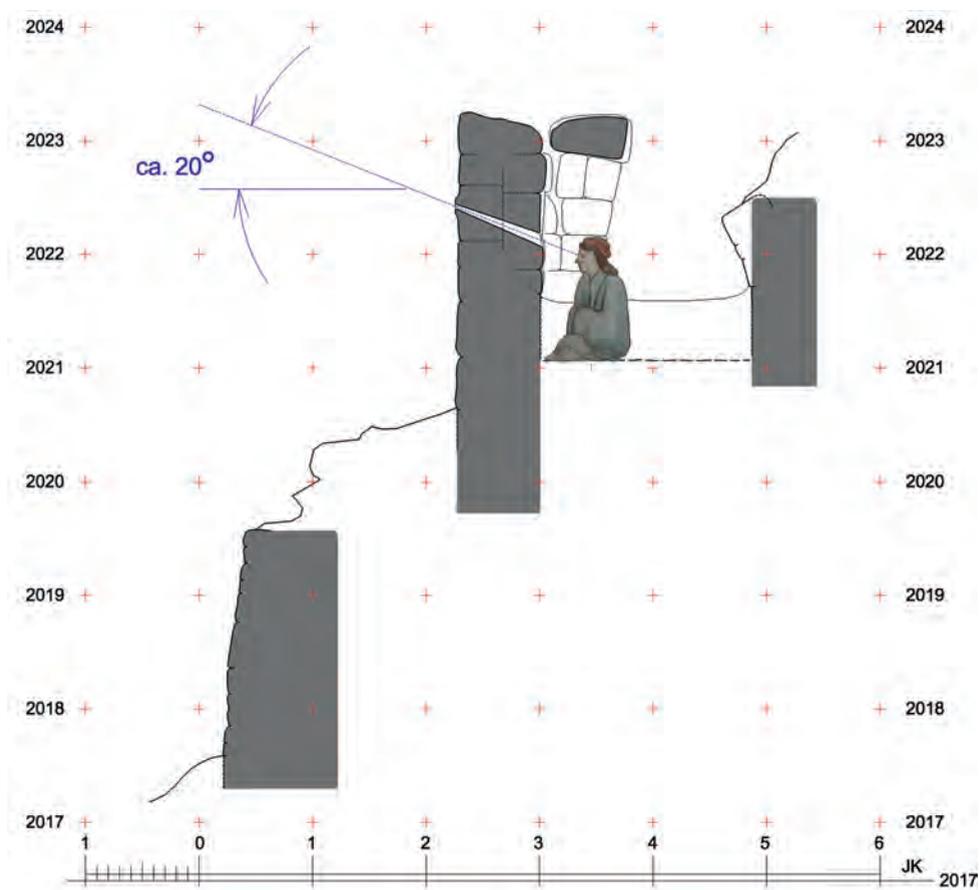


Figure 16. Vertical cross-section of the southern opening with the hypothetical reconstruction of a priest-observer position (drawing by Jacek Kościuk).

historical sources: “*They say of the Goats [the Pleiades], when they approach large: ‘This year we will have an abundant crop.’ And when they come quite small, it is said: ‘There will be a great misery.’*” (Taylor 1999, Chap. 29: 378-379 [1608] – English translation by the Authors).⁷

3) Could these openings have been used for the observation of other celestial bodies? Here we rely on guesswork, because while we have confirmation in numerous historical sources of the meaning of the Sun and the Pleiades in the Inca cosmivision and information practice, so far relatively little is known about the Inca “sky map” and the importance of individual stars. Although the rising of several bright stars, for example, Arcturus (α Boo) or Hamal (α Ari) was seen through the openings, we cannot be sure whether their observation was of interest to the Inca priest-astronomers. It may be worth noting, that the farthest north range of sight from the northern opening (approximately $Az = 54^{\circ}30'$) corresponds almost exactly with the position of Venus rising in the maximum northern declination, against a very distinctive rock formation (compare Fig. 14 left). Venus, as we well know from historical sources, was the object of special devotion in the Inca Empire, as a manifestation of the Lord of Thunder, the Holy twin of the Incan emperor (Szemiński and Ziółkowski 2015: 166-170).

In conclusion to this abbreviated presentation of Inkaraqay – El Mirador, allow us to quote one of the historical evidences concerning the Inca devices for gnomonic observation that were to have existed near Cuzco:

“And so that the time of planting and harvesting would be known precisely and never lost he [Pachacuti Inca Yupanqui] ordered there be placed on a high hill to the east of Cuzco four posts, separated from one another by about two varas [ca. 1.7 m – the Authors] and through their tops [were] some holes, through which the Sun entered like a clock or astrolabe. And considering where the sunlight fell through those holes at the time of fallowing and planting, he made marks on the ground [...]. And as he had adjusted these posts precisely, he put for permanence in their place some stone columns with the [same] measurements and holes as the posts, and all around he ordered the ground paved, and on the stones made certain leveled lines conforming to the movements of the sun which entered the holes [...]. And he delegated people to take charge of these clocks [...].” (Sarmiento de Gamboa 1906, Chap. 30 [1572] – English translation according to Bauer and Dearborn 1995: 37).

So far, the possibility of the existence of such a device was questioned by the scientific community, which viewed the quoted description with scepticism, as a product of its author, Pedro Sarmiento Gamboa’s, imagination. According to the critics, the chronicler used his knowledge of astronomy (he was the king’s cosmographer and navigator) for embellishing accounts of Inca astronomical knowledge (Bauer and Dearborn 1995: 36-37). But now, in the light of the Inkaraqay – El Mirador findings, this description becomes plausible. It is worth noting, that the dimensions of the structure, and especially the distance between the observation openings

(“two varas” = ca. 1.70 m) mentioned by Sarmiento de Gamboa, correspond almost exactly with what we found in Inkaraqay – El Mirador (1.75 m). This may be the result of pure coincidence. But there is another possibility, that the Incan astronomers have developed a certain model of an observation instrument, reconstructed in different places of the Empire, with modifications adapted to local conditions.

Acknowledgments

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The field works at Inkaraqay – El Mirador were done with the collaboration of César Medina Alpaca and José Bastante (Parque Arqueológico Nacional de Machu Picchu, Dirección Regional de Cultura, Cusco).

Notes

- ¹ The advances of the studies on Inkaraqay have been presented by the Authors on different occasions since 2014, among others, at the 54th Annual Meeting of the Institute of Andean Studies at Berkeley, California, January 10 – 11, 2014. A short communication about this discovery was published in November 2017 in a bilingual, Spanish-English version (Astete, Ziółkowski, Kościuk, 2017). The present, much more complete study, has been presented at the INSAP-X/Oxford-XI/SEAC-25th Conference « The-Road-to-the-Stars » that took place in Santiago de Compostela, Spain, between September 18 and 22, 2017.
- ² The famous observatory of Chankillo (Peru) is much earlier (ca. 300 BC) and there are no proofs that the Incas had inherited this tradition (Ruggles and Ghezzi 2007).
- ³ The side walls, as well as the back wall of this niche are badly damaged, but our careful examination of original stones scattered around excluded the possibility that any opening similar to those which are in the other niches ever existed, so the designation for this niche cannot be clearly explained.
- ⁴ Dimensions of all the niches only roughly correspond with Kendall typology of trapezoidal niches (Kendall 1985: 31-35).
- ⁵ The final 3D scanning of the general layout of the building was done by Jacek Kościuk and Ciechosław Patrzalek from Laboratory of 3D Scanning and Modeling with Leica P40 scanner. The same team executed the photogrammetrical project. Scanning of building details (both observational niches and openings) was done by Jacek Kościuk and Marta Pakowska from the same laboratory.
- ⁶ There are no radiocarbon dates available from this site, nor diagnostic archaeological materials. The approximate chronology was determined on the base of stylistic analysis of the architecture.
- ⁷ This refers to the brightness of this group of stars for the observer. Incidentally, recent studies have shown that this seemingly purely “magical” method of divining has a pretty solid basis and is highly effective. It turned out that the visibility of the Pleiades during their heliacal rising (beginning of June) is determined by the amount of water vapour in the upper atmosphere: poor visibility is due to high saturation, which in turn is usually a harbinger of climate change defined as the phenomenon of El Niño (ENSO), which in mountain areas causes drought, while on the Pacific coast disastrous rainfall. The correlation between these phenomena (the terms of the visibility of the Pleiades and ENSO) lays between 0.75 to 0.95, which means that the traditional forecasting methods were highly effective (Orlove et al. 2000).

References cited

- Astete Victoria, Fernando; Mariusz Ziółkowski and Jacek Kościuk
2017 Discovery of an inca precise astronomical observatory at el Mirador de Inkaraqay, Machu Picchu/El descubrimiento del observatorio astronómico inca del Mirador de Inkaraqay In: *El Top Anual de los grandes descubrimientos del Perú*, Ministerio de Cultura, Lima, pp. 576-595
- Aveni, Anthony F.
1981 Horizon Astronomy in Incaic Cuzco. In *Archaeoastronomy in the Americas*, edited by Ray A. Williamson, pp. 305-318. A Ballena Press/Center for Archaeoastronomy Cooperative Publication, Los Altos – College Park.
- Aveni, Anthony F., Sharon L. Gibbs and Horst Hartung
1975 The Caracol Tower at Chichen Itza: An Ancient Astronomical Observatory? *Science* 188: 977-985.
- Bauer, Brian S. and David S. P. Dearborn
1995 *Astronomy and Empire in the Ancient Andes: The Cultural Origins of Inca Sky Watching*. University of Texas Press, Austin.
- Ghezzi, Ivan and Clive Ruggles
2007 Chankillo: A 2300-Year-Old Solar Observatory in Coastal Peru. *Science* 315 (5816): 1239-1243.
- Kendall, Ann
1985 *Aspects of Inca Architecture: Description, Function and Chronology*. BAR International Series 242. British Archaeological Reports, Oxford.
- Orlove, Benjamin S., John C. H. Chiang and Mark A. Cane
2000 Forecasting Andean rainfall and crop yield from the influence of El Niño on Pleiades visibility. *Nature* 403: 68-71.
- Sarmiento de Gamboa, Pedro
1906 [1571] Segunda Parte de la Historia General Llamada Índica. In *Geschichte des Inkareiches von Pedro Sarmiento de Gamboa*, edited by Richard Pietschmann. *Abhandlungen der Königlichen Gesellschaft der Wissenschaften zu Göttingen, Philologisch-Historische Klasse, Neue Folge, Band VI n° 4*. Weidmannsche Buchhandlung, Berlin.
- Szemiński, Jan and Mariusz Ziółkowski
2015 *Mythes, rituels et politiques des Incas dans la tourmente de La Conquista*. L'Harmattan, Paris.
- Taylor, Gerald (editor)
1999 [1608] *Ritos y tradiciones de Huarochirí del siglo XVII. Manuscrito quechua de comienzos del siglo XVII*. 2nd ed. rev. Instituto Francés de Estudios Andinos/Banco Central de Reserva del Perú/Universidad Particular Ricardo Palma, Lima.

- Ziółkowski, Mariusz, Jacek Kościuk and Fernando Astete Victoria
2013 Astronomical Observations at Intimachay (Machu Picchu): A new approach to an Old Problem. *In Ancient Cosmologies and Modern Prophets. Proceedings of the 20th Conference of the European Society for Astronomy in Culture*, edited by Ivan Sprajc and Peter Pehani, pp. 391-404. Slovene Anthropological Society, Ljubljana.
- 2014 Inca Moon: Some Evidence of Lunar Observations in Tahuantinsuyu. *In Handbook of Archaeoastronomy and Ethnoastronomy*, edited by Clive L.N. Ruggles, pp. 897-912. Springer Science+Business Media, New York.
- Ziółkowski, Mariusz
2015 *Pachap Unancha. El calendario metropolitano del Estado Inca*. Ediciones El Lector/Sociedad Polaca de Estudios Latinoamericanos, Arequipa.