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3pAAa1. Whispering gallery at Chichen Itza's Great Ballcourt: Modern anomaly or original feature?

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A "whispering gallery" (WG) at the Great Ballcourt (GBC) was first reported during its excavation in the 1920s by the storied American archaeologist Silvanus Morley (1883-1948), Director of Carnegie Institution's Chichen Itza project. In a 1925 National Geographic's article he wrote: "Standing in this temple one can speak in a low voice & be heard distinctly at the other end of the court, 500 feet away." About 75 years later (2001), Mesoamerican archaeologists posting on a discussion group stiffened at the suggestion that the ancient Maya possessed the requisite knowledge for intentional acoustic design. An original WG, if any, was surely a design accident. Morley's WG was dismissed as a meaningless artifact of reconstruction or ageing. Contemporary reports of WGs and other sonic effects were also dismissed. Some disbelieved that WGs exists today! At a tour of Chichen Itza following the fall 2002 joint acoustical meeting in Cancun, Mexico, the author and his colleagues convincingly demonstrated the WG to about 100 acousticians and their companions. This paper describes WGs and other remarkable acoustic phenomena at the GBC. Its acoustical reading of GBC architecture suggests the WG was present originally. Cultural motivations and opportunities for intentional design are discussed.

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INTRODUCTION

Archaeology is described as the study of disappeared civilizations through examinations of their physical remains. It is sometimes described more briefly (if incompletely) as the study of “stones and bones”. That understanding offers little opportunity to study the *sound world* of disappeared civilizations. Sound, being famously ephemeral, is not usually regarded as a *physical remain*. But archaeological recreations that ignore sound are unsatisfying and incomplete. Imagine what is lost by describing our civilization as if its human and animal inhabitants were deaf.

Fortunately, a case can be made for including *sound* among the physical remains of disappeared civilizations. By doing so, acoustics can add value to archaeological findings. Acoustics can employ archaeological knowledge of ancient built environments to discover its inhabitant’s uses for sound. It can sometimes discover and recreate sounds heard in and around ancient temples, plazas and other structures, and even ancient soundscapes. Archaeological reconstructions tend to emphasize the visual at the expense of sound, olfactory, tactile, and gustatory phenomena. The recent trend toward *sensory archaeology* encourages efforts to include these underreported elements.

Ancient cultures evolved in a quieter world. Many subtle sounds valued by ancients are unnoticed or undetectable in modern times, especially the sounds of nature. Chronic noise exposure promotes a tendency to disregard sound. When cultures or habitations becomes noisy, its inhabitants have a natural tendency to emphasize vision over hearing. The quieter culture of the ancient Maya allowed greater attention to sound than do modern historians seeking to understand their culture. It is plausible that ancient built environments reflect greater attention to sound in ways that seem inconceivable to moderns. Perhaps that explains some Mesoamerican archaeologists’ disbelief in the plausibility of intentional acoustic design at Chichen Itza.

MAYA BALLCOURTS

The great importance of the ballgame in Mesoamerica is suggested by the fact that 1,560 known Mesoamerican ballcourts were documented by the year 2000 [1]. Of these, 225 or 14.4% were found at Maya lowland sites. Ballgames at small courts were used casually, often for exercise. Ballgames were played at larger ballcourts. But the largest ballcourts were also used for religious ceremonies and rituals. Some larger ballcourts were “effigy courts”, where games were ritually enacted but not played. Some Mayanists propose that the GBC was an effigy court.



FIGURE 1. Classic Maya Ballcourt at Copan. The sloping aprons of typical classic period ballcourts make them poor candidates for complex sound effects such as whispering galleries and flutter echoes.

BALLCOURT ARCHITECTURE

Considering the Mesoamerican ballgame's antiquity and ubiquity it should be no surprise that its architecture has evolved over time and place. A Mesoamerican ballcourt "typology" has been proposed, based on floor plan, and transversal (cross-section or elevation view) and longitudinal profile (plan view). About nine types are recognized, with variations within each type. [4]

THE GREAT BALLCOURT AT CHICHEN ITZA

Architecture of the Great Ballcourt (GBC) at Chichen Itza

The largest known Mesoamerican ballcourt is Great Ballcourt at Chichen Itza (GBC), FIGURE 2. Its architecture (Type III) is identified with the Terminal Classic and Early Post Classic periods. But its plan is much larger (96 by 30 m) and much taller (over 8.5 m) than other ballcourts. It is architecturally distinct from typical classic ballcourts, and its unusual acoustics are a result of those differences.

The two parallel walls comprising its playing field are about 83 m long and about 36.3 m apart. Stages of the north temple (seen at the top of FIGURE 3.) and south temple (bottom) are about 6 m high and 140.2 m apart. Vaulted ceilings of end temples are collapsed, but the back and side walls of the temples remain intact. Temples are centered on the ballcourts longitudinal axis. It's worth mentioning that earlier courts with parallel vertical playing walls like the GBC (without end temples) were known much earlier (Late Formative period).



FIGURE 2. The Great Ballcourt (GBC). Observe that the long playing field and the north and south temples are centered on the ballcourts longitudinal axis. The playing field's precisely parallel sound-reflecting walls are central to its whispering galleries, and are responsible for other interesting sound effects heard there. The playing field is modeled as a parallel plate acoustic waveguide. Sound from the temple is captured at the playing field entrance and propagates down its longitudinal axis as a plane wave. This prevents the captured wave from weakening by spreading. Propagation losses from the playing field terminus to the receiving temple is relatively low because the terminus is in the nearfield of the receiving temple.

MAYAS TOOK NOTICE SENSORY PHENOMENA IN BALLCOURTS AND OTHER RITUAL SPACES

“The ancient Maya and other Mesoamerican peoples showed an intense interest in invoking the senses, especially hearing, sight, and smell.” So wrote archaeologists Steven Houston and Karl Taube in the abstract to “An Archaeology of the Senses: Perceptions and Cultural Expression in Ancient Mesoamerica” [1]. An example of their attentiveness to ballcourt sounds is expressed epigraphically as *speech scrolls* in Mesoamerican art.

Speech scrolls are illustrative devices used to denote speech, song, or, as recently recognized, other types of sound discussed here. As advocates of Mesoamerican sensory archaeology, Houston and Taube have found evidence that Maya were aware of ballcourt “echoes and vibrant sounds” depicted as speech scrolls.

Formerly, all of the squiggly lines in the ballcourt scene of FIGURE 3 were identified as speech scrolls. But soon after this author called public attention to echoes at the GBC, Houston and Taube reinterpreted the “stray” scrolls (those detached from human lips in the figure) as “symbols for “echoes and vibrant sounds” in the late classic ballcourt scene of FIGURE 3 [2].

But as explained below, echoes must have been weak or uncommon at typical classic period ballcourts with sloping sides. They are profound at the GBC because strong flutter echoes are produced by its parallel playing field walls. So the “vibrant sounds” of the stray speech scrolls of FIGURE 3 may be directly radiated sounds of the ball impacting walls and players.

One Maya name for the ballgame is “pok-ta-pok”, an anamanapoetic word that evokes the sound of hard rubber balls striking stone walls, or possibly ballplayers hard, protective yokes [3]. Compare with the name “ping-pong” for table tennis which evokes the *two* sounds made when the ball first strikes a players paddle and then the tennis table. Imagine how impoverished the game of baseball would be without the “crack of the bat”. These examples demonstrate that sounds of play are inextricably linked with their games. Such sounds convey *information* to players and spectators, and increase the enjoyment of play.

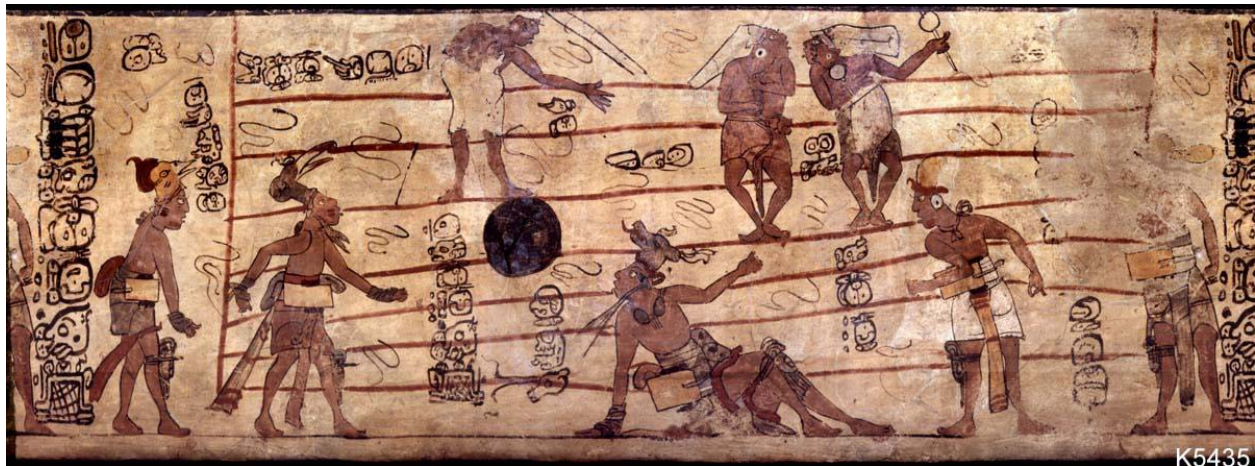


FIGURE 3. Ballcourt echoes were represented as *speech scrolls*, shown by the *stray* squiggly lines in this classic period ballcourt scene. Houston-Taube wrote: *In one image, set in a ballcourt, the artist showed echo effects in architectural spaces through the expedient of stray speech scrolls detached from human lips (Their Fig 14a). The convoluted, tightly bent, and modulated quality of these scrolls may denote echoing intensity of the sound.”*

Mythic Significance of Sounds of Play in Maya Ballcourts

Some solemn religious aspects of play in Maya ballcourts and their connections with sound are documented in the *Popol Vuh* (Quiche’ Maya creation legend) [5]. In it, two of the first humans were brothers and obsessive ballplayers. One day they played in a ballcourt on the road to “Xibalba” (Place of Fear), ruled by the twelve Lords of the Underworld. Unknown to the brothers, the sounds of play (e. g., running feet and ball strikes) awakened and disturbed those Lords (gods) who dwelled under that ballcourt. Aiming to punish these mortals for their insolent noisemaking, they invited the brothers to compete against them in their ballcourt at Xibalba. The brothers accept. Gaming against the gods, they lose and are sacrificed. One brother is buried under the ballcourt. The other is decapitated and his head flung onto a tree near the ballcourt. Despite these handicaps the decapitated brother

manages to impregnate an Underworld Lord's daughter by spitting on her palm. Twins (known as the "Hero Twins"), are borne of this encounter between a mortal and the daughter of a god. The Hero Twins grow up to become obsessive and skillful ballplayers. They challenge the Lords of the Underworld to a ballgame, and defeat them with skill and guile. Thus, according to the Popol Vuh, ballcourts were places of encounter between humans and gods from earliest times.

Understandably, ballcourts were seen as sacred spaces by the Maya. *Therefore, sounds heard in ballcourts might be understood as magical encounters between Mayas and their gods or ancestors.*

Maya theology shows that sounds of ballcourt play can evoke thoughts of supernatural beings of the underworld, blood sacrifice, contact with dead ancestors, and the cosmic human struggle. This made ancient Mayas vulnerable to mind manipulation through sound magic. Ballcourts with special sound effects could be valuable to Maya rulers.

GBC Whispering Galleries Present at the Reconstructed GBC are Believed to be Present Originally

Despite the doubts of certain Maya archaeologists, it is beyond dispute that WGs and other sonic effects at the GBC exist today. But were they present originally? Doubters argue that the presence of original WGs is unlikely because not all original materials and construction details have been preserved. The author suggests that this belief is mistaken and not informed by elementary knowledge of architectural acoustics.

The author believes that WGs were originally present *if the reconstructed GBC is reasonably faithful to the original.*

The author's acoustical analysis shows two *necessary* conditions for current and original WGs are that:

- (1) Playing field walls must be precisely parallel
- (2) Playing field walls must be highly sound reflecting.

It is demonstrable that both conditions exist presently. The author contends that they also existed originally.

Playing field walls are precisely parallel today. This is proven by the long flutter echo (>1.5 s) of impulsive sounds made between those walls. The flutter echo would be absent or much shorter and weaker if playing field walls were not parallel, e.g., tilted vertically in opposite directions by more than say, two or three degrees. This fact is well-known by acoustical consultants. Flutter echoes are almost always unwanted design defects in modern architecture (exceptions include handball and jai-alai courts). But at the GBC it is apparently a design feature!

If the GBC was excavated without moving or tilting the massive wall structure (as seems plausible) they were almost certainly parallel originally. They were parallel if as believed, ballcourt reconstruction was done with full archaeological and architectural integrity by its Carnegie Foundation architects. To the author's knowledge, the integrity of that reconstruction has never been questioned.

That playing field walls are highly sound reflective today is also proven by the flutter echo, which require that both facing walls be highly sound reflective AND parallel. It is believed that facing walls were reconstructed from bricks of original walls because, supposedly, traces of their original paintings are present on a facing wall. Since facing walls are sound reflective today, they were surely equally or more reflective originally. The ravages of time would be expected to roughen smooth walls. Roughened walls scatter sound. Some of the scattered sound is not available for reflection. So flutter echoes would be expected to be somewhat shorter now than originally.

Original Presence of Whispering Galleries is not proof of Intentional Design

The original presence of whispering galleries is not proof of intentional design. Lacking such proof one must remain open to the possibility - however remote - that original whispering galleries were mere design accidents.

WHISPERING GALLERIES OF THE GBC

Whispering Galleries Between Temple and Playing Field, and their Practical Uses

Fascinating WGs exist between temple stages and playing field. Speech communication between each temple and playing field was demonstrated to a group of about 100 acoustical scientists and engineers by the author and two colleagues after the First Pan-American/Iberian Meeting on Acoustics in December, 2002. Ballcourt walls eliminate wind noise, and while not yet demonstrated, may also attenuate noises originating from outside of the GBC.

If originally present, these WGs would allow officials on either stage to address teams on the playing field.

There is room for about three thousand persons standing 1 m apart in the large playing field. However, tests have not been made to learn if the sound absorption introduced by large numbers of people would reduce the upper limit. At the post-meeting demonstration in 2002, as many as 150 to 200 people were present without noticeable degradation.

Also, solitary persons on the playing field can be addressed by persons on the stage of either temple. This would provide opportunities for officials to perform “sound magic” for psychological manipulation of their subjects.

It would be a simple matter to arrange temple stages so officials speaking there would be invisible to playing field listeners. Solitary listeners would be impressed to hear disembodied voices that appear to originate nearby, though no person was visible. The ability to perform such sound magic could be useful for mind manipulation. Chichen Itza was a ceremonial city. Presumably, commoners would have no opportunity to discover these magical effects.

Whispering Gallery Between North and South Temples

The Great Ballcourt’s best known WG exists between its north and south temples. Persons standing near the center of each temple and speaking with normal voice effort can hear each other clearly at a range of 140 m. Such good speech communication would be impossible for two individuals on level ground. This empirical finding is supported by TABLE 1, which estimates, or makes educated guesses of each element of propagation loss between temples.

If originally present, kings and high official could address many subjects arrayed on the quiet playing field. The ability to address many subjects from a privileged temple location would surely be useful for sustaining rulership. The usefulness of GBC whispering galleries could have motivated their development.

Facing walls of the playing field may be original features and not reconstructions. GBC walls are so precisely parallel and so highly sound reflective that handclaps made at mid-playing field produce profound flutter echoes at voice frequencies. The echoes persist for 1.5 sec or longer, as shown in the sonogram of FIGURE 4. .

Traces of original paintings are rumored to be on facing playing field walls. If so, present walls are original. To be so highly reflective, wall surfaces must be nonporous and smooth. The ravages of time would make them slightly less smooth today. If so, wall surfaces were originally slightly smoother and therefore even more sound reflective!

If the original walls were not disturbed in excavation, as seems likely, and if the original facing walls were equally sound reflective, as seems certain, then the profound flutter echo must have been present in the original ballcourt!

Other Interesting Sound Effects in the GBC Playing Field

In 1935, Morley invited two Maya revolutionary soldiers to visit the newly excavated ballcourt [6]. The soldiers shouted greetings to their ancestors at playing field walls. The flutter echo multiplied their greetings, which they thought was being returned by thousands of departed ancestors whose spirits resided in the ballcourt.

Morley told these soldiers that the (north?) temple of the GBC was once the office of the Maya king. Thereupon, the soldiers alighted opposite temples and enacted a dialogue across the 140 m length of the playing field. One soldier “channeled” the ancient king’s voice from his office, making note of the many “feathered serpents” adorning the temples of Chichen Itza – beings which, though stone, also live and await the day they may stir again [7]. These examples show that at least some traditional Maya beliefs have persisted to modern times.

A breathtaking binaural sound effect is heard when a person standing near a playing field entrance loudly whistles an upward chirp diagonally toward the opposite wall. The audible effect at mid-field is remarkable! Consecutive repetitions of the original whistle are heard. They seemed to originate from the whistler’s end of the playing field

and above my head. The repetitions grow louder as they work their way toward me. The loudest repetition occurs when the chirp is localized overhead. Subsequent chirps become progressively weaker until the source appears to reach the playing field opposite end. It was as if an invisible bird was flew along the playing field's longitudinal axis while chirping continuously. I suspect it is caused by the excitement of higher order waveguide modes.

The GBC seems a synthesizer of theatrical sound effects. The author believes that other effects await discovery.

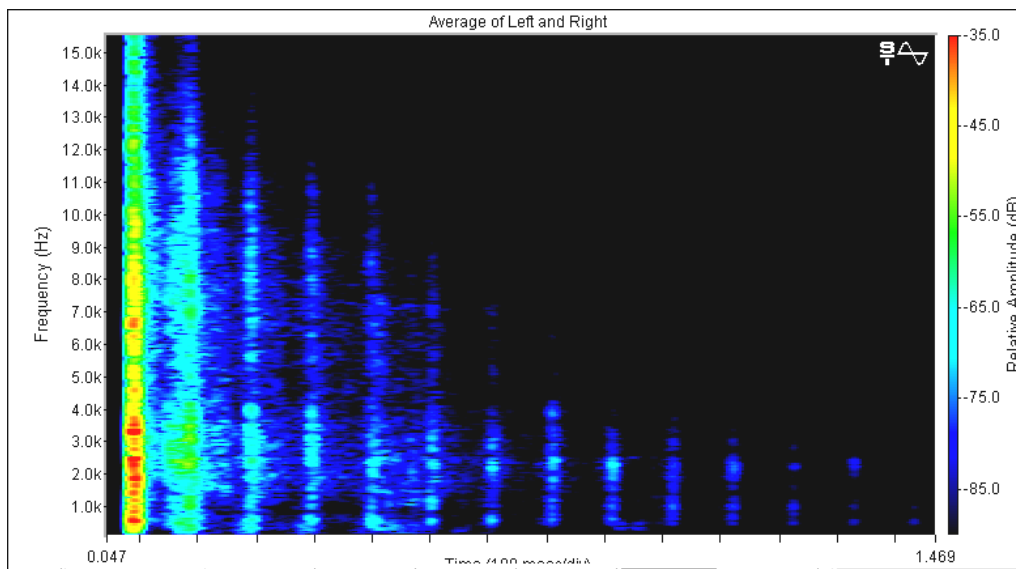


FIGURE 4. Flutter echo of a handclap made near the center of the playing field are proof that its facing walls are precisely parallel and highly sound reflective. The writer believes these massive walls were not moved in excavation. Since the facing walls display faded original paintings, they too are original surfaces. As shown by the profound flutter echo, the walls are highly sound reflective at voice frequencies [8], [9].

OUTLINE OF MODEL TO EXPLAIN GBC WHISPERING GALLERY AND OTHER SOUND EFFECTS

With only brief opportunities to experiment with GBC acoustics, the following is largely speculation.

The main elements of the WG between end temples are the temples themselves, the playing field walls, and their rather precise orientation along the ballcourt longitudinal axis.

The playing field's smooth vertical walls is modeled as a *parallel plate acoustic waveguide* whose smooth interior walls assure low attenuation. The temples are modeled as facing proscenium stages.

Sound emanating from a talker standing near the center of the temple stage and on the ballcourts longitudinal axis is weakened by spreading until it impinges on the playing fields entrance. Above the waveguide's cutoff frequency spherical sound radiation is efficiently coupled to the playing field and propagates to the opposite end as plane waves. Constraining the wave prevents further spreading loss. But the wave is subject to other (waveguide) losses.

Efficient sound coupling from temple stage to playing field and then from playing field terminus to receiving temple is facilitated by locating temple source and receiver positions on the ballcourts longitudinal axis.

It is speculated but not known that sound arriving at a playing field's entrance from off-axis is less efficiently coupled to the waveguide. If true, it would tend to isolate playing field (and receiving temple) from exterior noises.

However, sounds originating from within the playing field produce profound echoes there, which may have disorienting and hallucinatory effects on its occupants. Sound directed perpendicular to walls produce flutter echoes

while sound striking walls from off-axis propagate as higher modes, which have lower group velocity. It is proposed that the higher modes can explain the fascinating binaural sound effect described above.

Plane wave ground attenuation is reduced if the plane wave terminates at “bench” height, about 1.7 m above ground level. Not coincidentally, that corresponds roughly to head height for persons in the playing field

The plane wave exits the waveguide and propagates to the receiving temple - but with low spreading loss. The temple-to temple path with the highest spreading loss (29 dB) is from sending temple to the playing field entrance – a distance of about 28.7. The high loss owes to spherical spreading from a point source (talker at the source temple). But another advantage of conversion to a plane wave with a large aperture is that spreading loss from the playing field’s terminus to receiving temple is far less. This may seem surprising because of the near left-right symmetry of the GBC. But because the large aperture of at the playing field terminus, the receiving temple is in the nearfield at voice frequencies. It is known that to an equal distance. Nearfield spreading loss for a large is far less than for a point source.

Assume the nearfield/farfield boundary is at a distance R, where

$$R = D^2/\lambda = fD^2/c, \quad (1)$$

where D is the aperture size (36.3 m distance between ballcourt walls), λ is the wavelength (3.43 m @ 100 Hz) and c is the speed of sound in air (343 m/sec).

Then $R \gg$ distance from terminus to receiving temple for voice frequencies and above. Thus the receiving temple is in the nearfield of the playing field terminus. The spatially coherent plane wave at the terminus can thus be modeled as a planar array of coherent point sources.

TABLE 1 illustrates these ideas. “Its “Guestimates” can become “estimates” with testing and numerical modeling.

TABLE 1. This exercise shows that the GBC whispering gallery has an estimated 22 dB advantage over free field voice communication on the same 140 m path. Also ambient and wind noise is lower in the WG because of its shielding walls.

Element	Element/Path	Assumptions	Gain/Loss (+/-)	Notes
A	Talker on source Temple	Voice level: 67 dB(A) @ 1m	0 dB	Raised Voice Level
B	Stage Gain of both Temples [dB]	Sound reflecting interior walls, but no ceiling vault	+6 dB Guestimate	Interior walls hard & nonporous
C	Talker on stage to Playing Field entry [28.7 m]	Talker’s voice spreads spherically	-29 dB	$-20\log(28.7) = -29$ dB
D	Playing Field Entry	Loss for coupling spherical wave to plane wave [dB]	-3 dB Guestimate	Only plane wave mode survives. PF = Playing Field
E	Entire Length of Playing Field [83 m]	Ballcourt modeled as a leaky parallel plate waveguide	-5 dB Guestimate	WG attenuation & leakage - but no spreading loss
F	Playing Field exit to receiving temple	Receiving temple in NF of large coherent plane wave at PF exit	+10 dB Guess	NF = near field. PW wave 36.3 m wide X 6.8 m high = 247 m ²
G	Attenuation of Air	1 KHz, 20° C, 70% RH, 1 Atm.	-0.5 dB	
		Net Loss in WG	-21.5 dB	
		Received voice level in WG	45.5 dBA	67 – 21.5 = 45.5
		Speech to noise ratio in WG	+9.5 dB	Voices audible in WG!
Compare Whispering Gallery with free field (FF) spreading over level ground (Ignoring ground effects) Assume ambient noise level of 35 dBA for both cases				
		Spherical spreading loss in FF	-43 dB	140 m path over level ground
		Received voice level in FF	23.5 dBA	
		Speech to noise ratio in FF	-11.5 DB	Voices inaudible in FF!
		WG Advantage over FF	+22 dB	= 45.5 dBA – 23.5 dBA

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