

1 **Title**

2 **Recording of “sonic attacks” on U.S. diplomats in Cuba spectrally matches**
3 **the echoing call of a Caribbean cricket**

4

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14

15 **Beginning in late 2016, diplomats posted to the United States embassy in Cuba began to**
16 **experience unexplained health problems—including ear pain, tinnitus, vertigo, and**
17 **cognitive difficulties¹⁻⁴—which reportedly began after they heard^{1,2} strange noises in their**
18 **homes or hotel rooms. In response, the U.S. government dramatically reduced¹⁻³ the**
19 **number of diplomats posted at the U.S. embassy in Havana. U.S. officials initially**
20 **believed^{1,2,5} a sonic attack might be responsible for their ailments. The sound linked to**
21 **these attacks, which has been described as a “high-pitched beam of sound”, was recorded**
22 **by U.S. personnel in Cuba and released by the Associated Press (AP). Because these**
23 **recordings are the only available non-medical evidence of the sonic attacks, much attention**
24 **has focused on identifying health problems⁶⁻¹¹ and the origin¹²⁻¹⁷ of the acoustic signal. As**
25 **shown here, the calling song of the Indies short-tailed cricket (*Anurogryllus celerinictus*)**

26 **matches, in nuanced detail, the AP recording in duration, pulse repetition rate, power**
27 **spectrum, pulse rate stability, and oscillations per pulse. The AP recording also exhibits**
28 **frequency decay in individual pulses, a distinct acoustic signature of cricket sound**
29 **production. While the temporal pulse structure in the recording is unlike any natural insect**
30 **source, when the cricket call is played on a loudspeaker and recorded indoors, the**
31 **interaction of reflected sound pulses yields a sound virtually indistinguishable from the AP**
32 **sample. This provides strong evidence that an echoing cricket call, rather than a sonic**
33 **attack or other technological device, is responsible for the sound in the released recording.**
34 **Although the causes of the health problems reported by embassy personnel are beyond the**
35 **scope of this paper, our findings highlight the need for more rigorous research into the**
36 **source of these ailments, including the potential psychogenic effects, as well as possible**
37 **physiological explanations unrelated to sonic attacks.**

38
39 Additional embassy personnel reported hearing sounds at night¹⁻⁵ and many were sent to the U.S.
40 for medical evaluation. A team from the University of Pennsylvania presented⁴ evidence of
41 medical abnormalities. The U. Penn. paper has however been criticized as using an arbitrarily
42 low threshold for neurological impairment⁶⁻⁸ and improperly ruling out potential causes such as
43 functional neurological or psychological disorders⁹⁻¹¹.

44
45 United States personnel made multiple recordings of the distinctive sound and these recordings
46 were played to embassy personnel so they would know what to listen for⁵. The Associated Press
47 (AP) received several of these recordings and posted⁵ one representative sample online.
48 Recordings were sent⁵ to the U.S. Navy and FBI for analysis, and some were made available¹² to
49 the Cuban government. Because these recordings are the only non-medical evidence available on
50 the “sonic health attacks” in Cuba, much attention has focused on identifying the origin of this

51 acoustic signal, and on establishing whether it is connected to the reported health outcomes. A
52 Cuban government report suggested¹² that the Jamaican field cricket *Gryllus assimilis* was
53 responsible. Other researchers posited that the noise might be¹³ the byproduct of a beam of high-
54 power microwave-pulsed radiation. Another team suggested¹⁴⁻¹⁷ that intermodulation between
55 ultrasound emitters could produce a spectral shape similar to the AP recording, and that this
56 audio signal may be a byproduct of malfunctioning eavesdropping equipment.

57

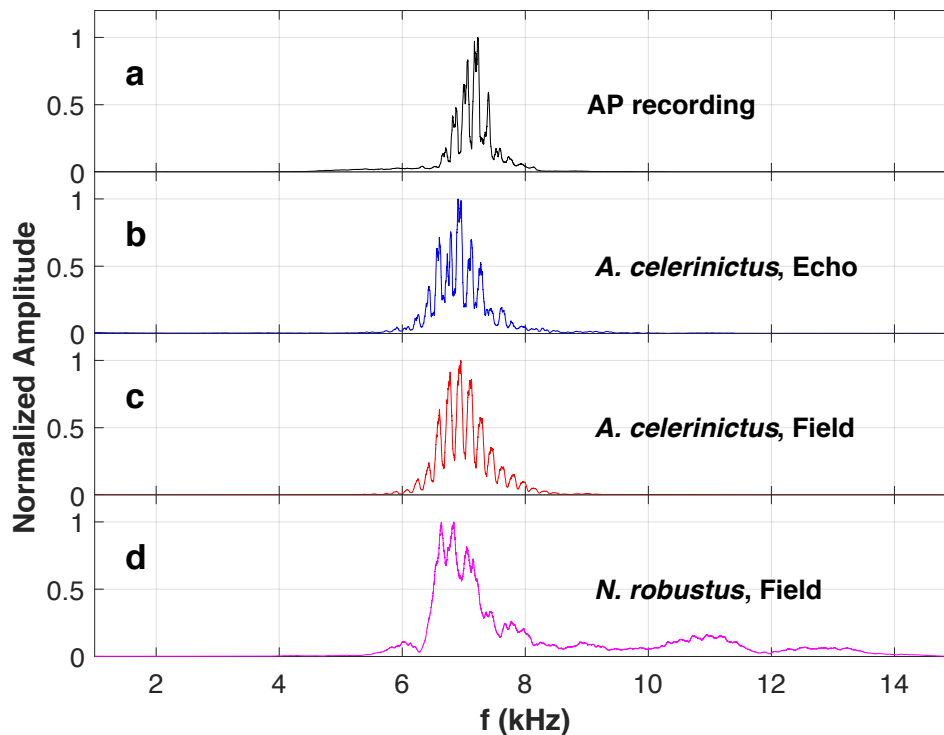
58 After listening to the AP recording A.L.S. was reminded of his experiences conducting fieldwork
59 in the Caribbean. The recording sounded like an insect, yet the pulse structure of the AP-released
60 file⁵ does not look like¹⁷ classic oscillograms presented in the biological literature on insect calls.
61 If an insect were responsible for the sounds recorded by U.S. personnel in Cuba, this should be
62 verifiable by quantitatively comparing recordings of calling insects to the AP sample.

63

64 Male crickets produced their calls by wing stridulation. One wing bears a vein with
65 systematically-organized indentations and the other a scraper. The wings open and close, but
66 only during the closing phase does the scraper strike consecutively each file tooth and produce a
67 pulse of sustained oscillations amplified by specialized wing cells. The entire sequence of
68 oscillation is known as a syllable. Therefore, a syllable is made of a number of oscillations that
69 match³¹ the number of teeth struck in the file. The structure of a pulse is affected by³² the
70 duration of muscular twitch and varying tooth spacing, which in conjunction with wing
71 deceleration cause a commensurate reduction in the frequency of tooth-strikes towards the end of
72 the pulse. Therefore, all cricket pulses in nature exhibit³³ a gradual reduction in the instantaneous
73 frequency as the pulse evolves.

74

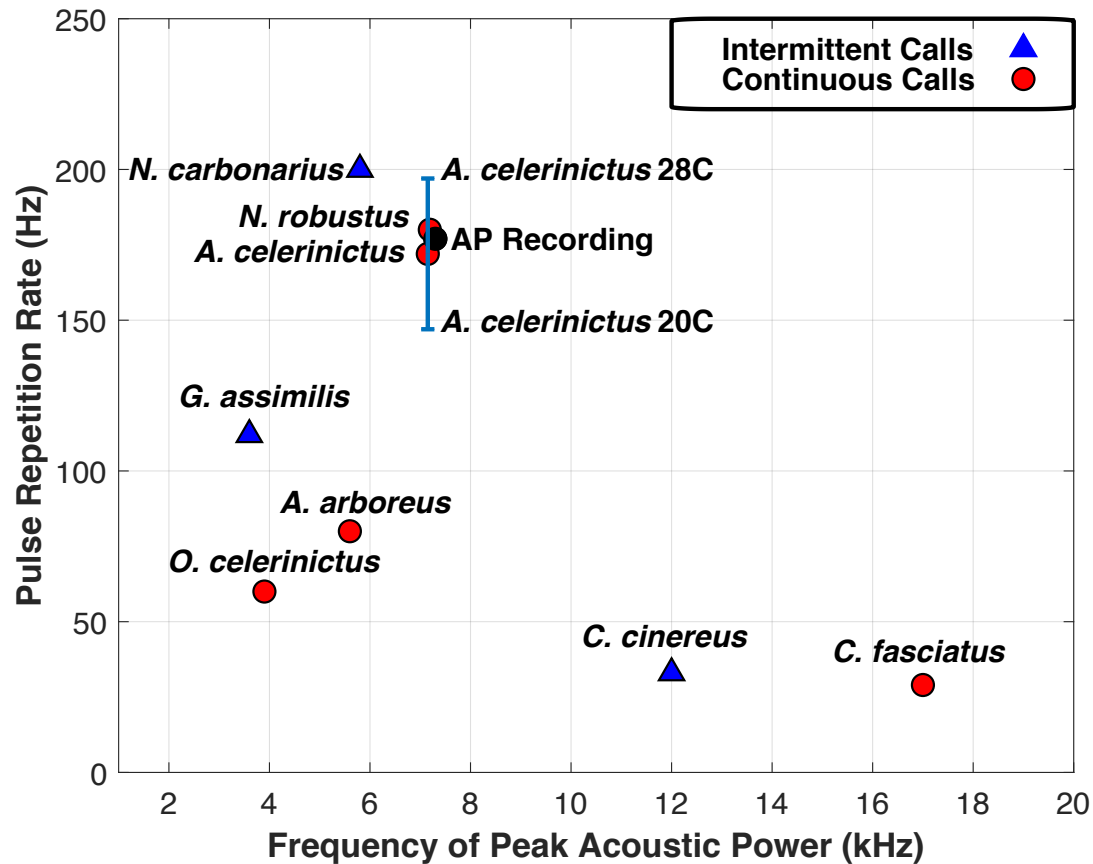
75 The recording released by the AP⁵ has a number of measurable parameters. The power spectrum
76 resembles a picket fence (Figure 1) with most of the power concentrated around 7 kHz. The
77 picket fence of emission occurs at integer multiples of the pulse repetition rate (PRR) of ~180
78 Hz. The sound is continuous for the duration of the recording.



79
80 **Fig. 1. Normalized amplitude spectrum of potential sound sources compared to AP**
81 **recording.** **a**, the AP-released recording from Cuba, **b**, recording of *A. celerinictus* played on a
82 speaker and recorded indoors, **c**, *A. celerinictus* and **d** the katydid *Neoconocephalus robustus*
83 recorded in the field. *N. robustus* has a broader spectral emission, with more power at higher
84 frequencies, than the cricket *A. celerinictus*. The distinctive picket fence structure in the
85 amplitude spectrum occurs at integer multiples of the pulse repetition rate (PRR), in this case
86 multiple of 180 for the A.P. recording and *A. celerinictus* recording with and without echoes.
87 The picket microstructure depends on PRR stability. Any proposed source must conform to both
88 the peak emission at 7 kHz and have sufficient PRR stability to produce this characteristic picket
89 fence structure in the amplitude spectrum.

90

91 The combination of a definitive carrier frequency (7 kHz) and PRR (180 Hz) allows for an
92 assessment of potential calling insect sources, as seen in Figure 2. A number of insect species are
93 capable of producing a 7 kHz carrier frequency, whereas a PRR as high as ~180 Hz is rare in
94 nocturnal insects that produce continuous calls. The PRR of many insects varies with
95 temperature, but the peak carrier frequency remains¹⁷⁻²⁴ comparatively stable. After an extensive
96 evaluation of online recordings, the katydid *Neoconocephalus robustus* (Scudder 1862) and
97 cricket *Anurogryllus celerinictus* (Walker 1973) calls were downloaded²² and analyzed for a
98 number of spectral parameters, as both were potential matches in carrier frequency and PRR (see
99 Methods). Both insects can call continuously, they share a peak carrier frequency of ~7 kHz, and
100 are capable of²⁰⁻²² a PRR of 180 Hz or above. Furthermore, *A. celerinictus* has²⁰ the fastest PRR
101 of any continuously-calling cricket in the Caribbean or North America, and *N. robustus* is²² the
102 loudest insect sound known from North America.



103

104 **Fig. 2. Pulse repetition rate vs. peak acoustic power frequency of various insect calls**
105 **compared to the AP-released recording from Cuba.** Both *A. celerinictus* and *N. robustus* are
106 capable of continuously producing a sound with peak power at 7 kHz modulated at a PRR of
107 ~180 Hz. Continuously-calling insects are shown as circles while those with intermittent pulse
108 trains are shown as triangles. The PRR's for these insects are temperature dependent, as shown
109 by the bar for *A. celerinictus*.

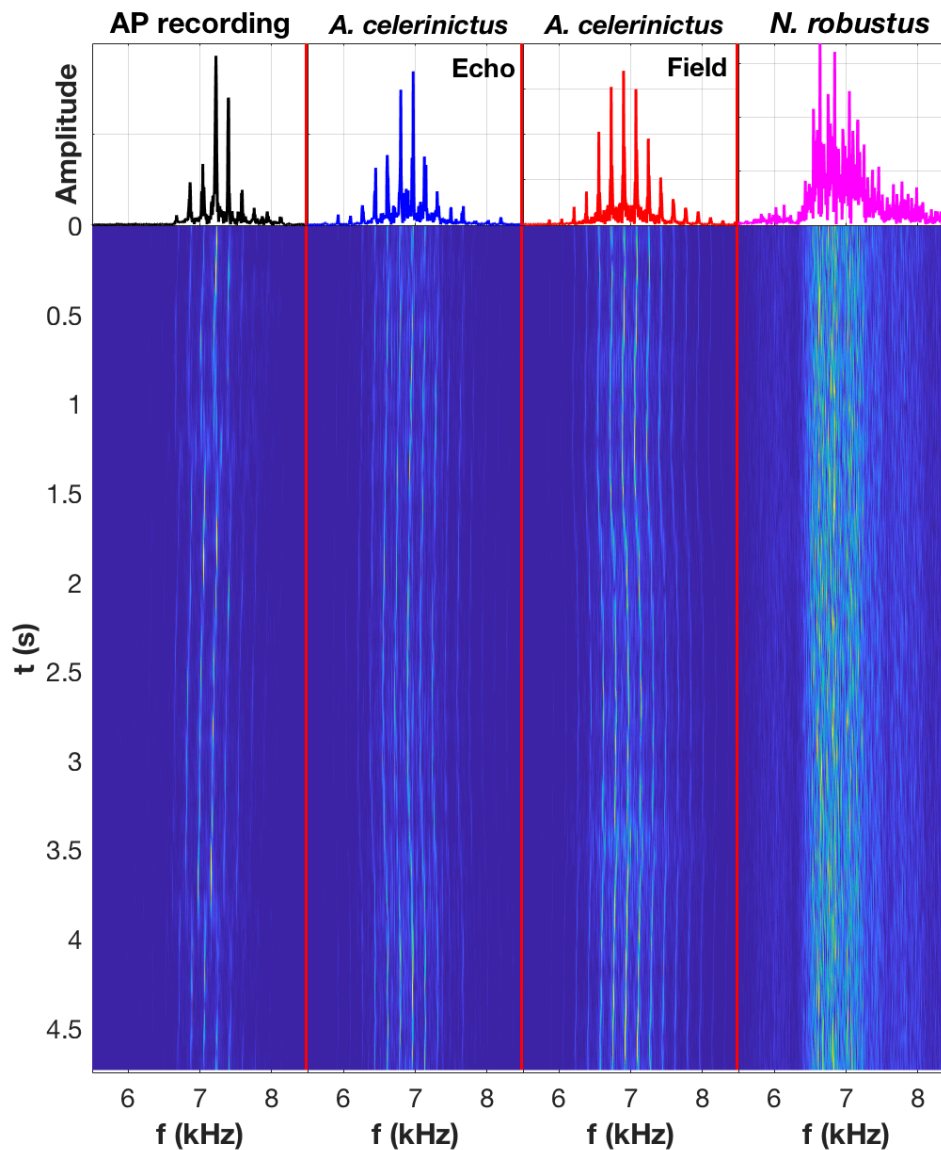
110

111 The Cuban government was given access¹² to multiple recordings by the U.S. government. The
112 Cuban report proposed¹² that the cricket *G. assimilis* was responsible for this sound. This insect
113 does not call continuously, but rather produces²²⁻²⁴ an intermittent somewhat melodic chirp once
114 per second. U.S. personnel on the other hand reported^{1,2} and recorded⁵ a continuous high-pitched

115 buzzing. Additionally, *G. assimilis* calls use a much lower peak carrier frequency of 3.6 kHz and
116 a PRR of less than 120 Hz^{3,6}, while the AP recording has a carrier frequency of 7 kHz (as do the
117 other audio samples analyzed¹² in the Cuban report) and a PRR of almost 180 Hz as seen in Fig.
118 2. Given that the specific organism identified¹² in the Cuban report fails on all quantitative
119 metrics to explain the sound recorded in Havana, and would sound qualitatively different even to
120 non-experts, it is understandable that U.S. authorities met this explanation with skepticism.

121

122 The picket fence structure in the power spectrum is determined by the stability of the PRR. This
123 is shown in Figure 3.



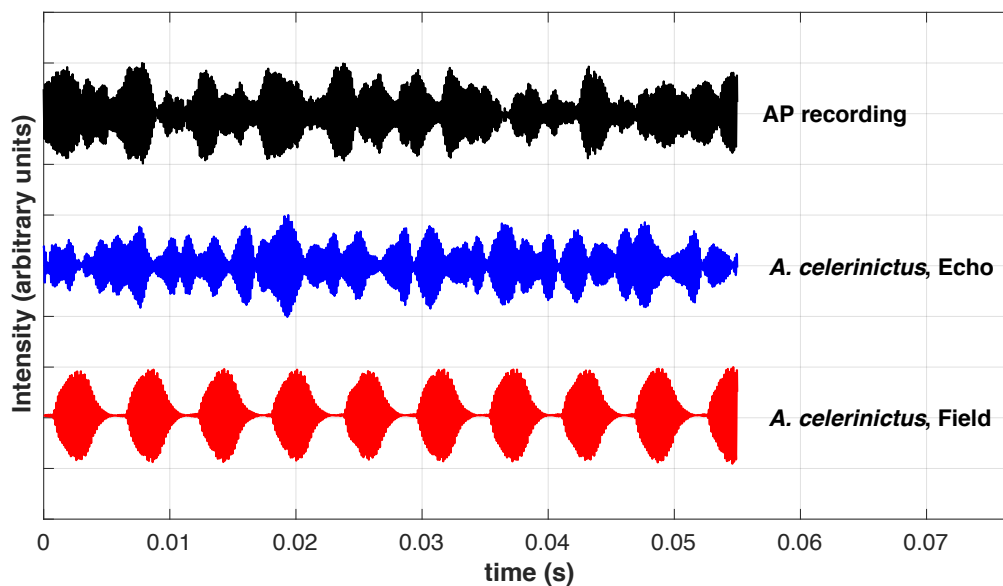
124

125 **Fig. 3. Plot of the pulse repetition rate stability.** The lower panels show the evolution of the
126 amplitude spectrum. Time runs vertically in the lower panel, and frequency increases to the right.
127 The plots at the top show a cut across the waterfall diagram at $t=0$. Each line in the diagram
128 comprises 8192 samples, spanning 186 msec. The AP recording and both recordings of *A.*
129 *celerinictus* exhibit relatively (but not perfectly) stable PRR, whereas *N. robustus* shows
130 significant short-term variability in PRR. The evolution of *A. celerinictus* matches the AP
131 recording; both show few-percent fractional variations in PRR on a characteristic timescale of
132 seconds.

133

134 The AP recording exhibits a non-uniform pulse structure (Figure 4) that at first glance is
135 inconsistent with field and lab recordings¹⁷⁻²² of calling insects. The AP recording has sufficient
136 variation in PRR (such as the offsets visible at 1.25 and 4 seconds) that it is unlikely to have been
137 generated by a regulated digital signal source. U.S. personnel in Cuba reported hearing^{1,2} these
138 sounds indoors. Ricocheting sound off walls, floors, and ceilings could produce complicated
139 interference patterns or “echoes” obscuring the original pulse structure. To test if this might
140 explain the pulse structure in the AP sample, a simple experiment was conducted. The *A.*
141 *celerinctus* field recording was played on a high-fidelity loudspeaker, and recordings were made
142 at various locations indoors. The pulse structure of a representative recording is shown in Fig. 4
143 and Extended Data Figure 1.

144



145

146 **Fig. 4. Pulse structure of AP recording and *A. celerinctus* with and without echo.** This plot
147 shows the pulse structure of the three recordings over time. The AP recording (**top, black**)
148 exhibits an irregular pulse structure that does not match insect calls from isolated field
149 recordings. The *A. celerinctus* call (**bottom, red**) is highly uniform in pulse structure when

150 recorded in the field however this is modified by internal echoes when recorded indoors. The *A.*
151 *celerinictus* call recorded indoors (**middle, blue**) is an excellent match to the AP recording in
152 pulse structure, pulse repetition rate, pulse repetition rate stability, and amplitude spectrum.

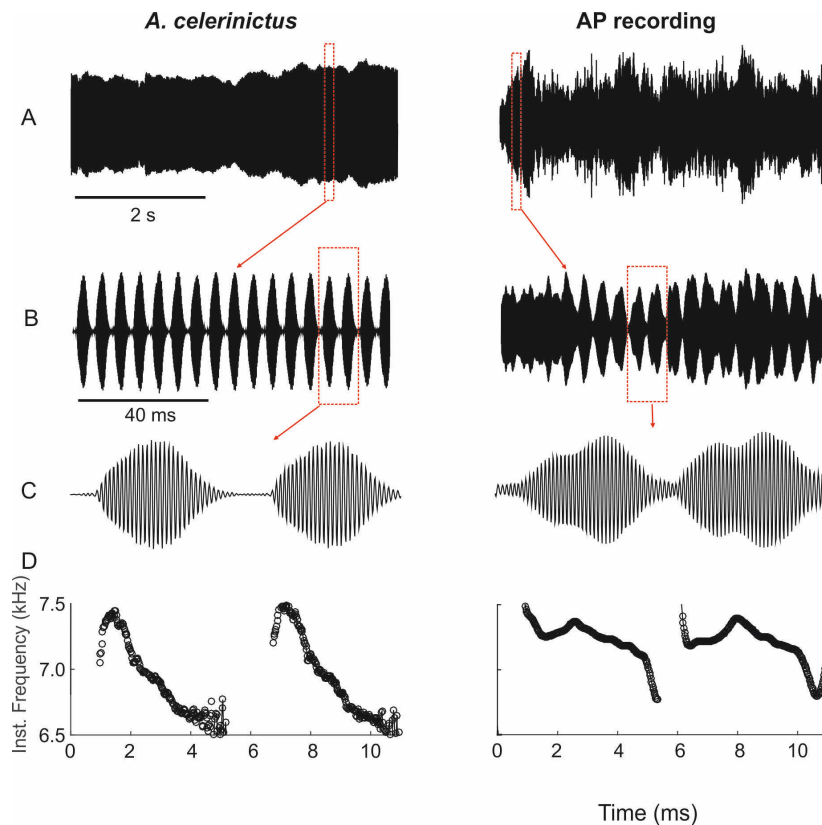
153
154 The pulse structure labeled “*A. celerinictus*, Echo” in the figures results from a recording made
155 in a house with tile floor and drywall construction. The pulse-envelope-structure of both the AP
156 recording and the recordings of an *A. celerinictus* call played indoors are not constant through
157 time, which can be due to complicated interference patterns that result from multiple sound
158 pulses superimposed on one another with pulse-to-pulse variation in the phases of the interfering
159 7 kHz components. Extended Data Figure 1 shows a longer timescale of pulse structures, and
160 Extended Data Figures 2 and 3 show quantitatively the similarity between the echoed *A.*
161 *celerinictus* call and the AP recording. Extended Data Figure 4 shows a similar resulting pulse
162 structure from an echoed recording of related *Anurogryllus muticus* obtained by A.L.S. in Costa
163 Rica from within a restaurant compared with a field recording of the same species. These
164 analyses all show that the pulse structure of the AP recording is consistent with an echoing
165 cricket call. A.L.S. also notes that while crickets calling away from structures were fairly easy to
166 locate, the complex sound environment and echoes made it very difficult to find individual
167 crickets calling near buildings.

168
169 In *A. celerinictus* the file has between 40-50 teeth spread over 2.5-3.0 mm²⁰, and the number of
170 cycles in each pulse is around 30 as shown in Figure 5. The number of oscillations per pulse for
171 the field recording of the insect matches that seen in the AP recording. This agreement is an
172 independent additional piece of evidence for *A. celerinictus* being the source of the sound in the
173 Cuba recording.

174

175 Figure 5 compares the decay of the instantaneous frequency over the course of a pulse. This is
176 due, in part, to deceleration of the cricket's wing through each pulse. While individual pulses in
177 the AP recording are impacted by echoes of the preceding sound pulse, there is a clear decay in
178 frequency in both cases.

179



180

181 **Fig. 5. Frequency evolution and number of oscillations within a pulse.** A, B, and C, show the
182 time series with a scale bar of 2 seconds, 40 ms and 4 ms respectively, for field and AP
183 recordings. Panel D shows the frequency decay through one pulse, measured via the interval
184 between zero crossings. In both the *A. celerinictus* recording and AP recording the frequency
185 decays over the sound pulse.

186

187 The 7 kHz buzzing sound recorded by U.S. embassy personnel and released by the AP is entirely
188 consistent with an echoing insect source, and not likely to have resulted from a “sonic attack.”
189 Other hypotheses that invoke stable digital signal sources¹³⁻¹⁶ for this sound (a) do not explain
190 the few-percent drift in the PRR, (b) are not as well-matched spectrally¹⁴, and (c) fail to explain
191 the pulse structure and frequency decay through each pulse seen in the AP recording. The first
192 individual to believe this sound was associated with health issues reported¹ that the sound
193 stopped abruptly when he opened the front door. This and other reports of the sound abruptly
194 stopping with movement in a room²⁵ are also consistent with an insect stopping a call when
195 threatened.

196
197 The situation in Cuba has¹ understandably led to concern and anxiety, and the sonic attack
198 hypothesis has gained widespread attention in the media. However, this paper shows that sounds
199 like those in the AP recording have a natural explanation. In particular, we have six lines of
200 evidence to show that the sounds recorded by U.S. personnel in Cuba correspond to the calling
201 song of a specific cricket, with echoes. The following quantitative signal characteristics provide
202 independent lines of evidence to support the conclusion that the sound recorded by U.S.
203 personnel in Cuba is of biological origin:

- 204 1. Carrier frequency of 7 kHz
- 205 2. Pulse repetition rate of 180 Hz
- 206 3. Timescale and amount of pulse repetition instability
- 207 4. Echo phenomenology
- 208 5. Number of oscillations per pulse
- 209 6. Frequency decay of about 1 kHz over pulse duration

210
211 Thus, while disconcerting, the mysterious sounds in Cuba are not physically dangerous and do
212 not constitute a sonic attack. The fact that the sound on the recording was produced by a
213 Caribbean cricket does not rule out the possibility that embassy personnel were victims of
214 another form of attack. While the causes of any signs and symptoms affecting U.S. personnel in
215 Cuba are beyond the scope of this paper, a biological origin of the recorded sounds motivates a

216 rigorous examination of other possible origins, including psychogenic, of reported neuro-
217 physiological effects. This episode has potential parallels with a previous incident in U.S.
218 history, “yellow rain” in Southeast Asia, where alleged chemical attacks were later determined to
219 be of benign biological origin. In that instance bees, rather than crickets, were to blame.

220

221

222

223

224 **Methods**

225 **A: The search for a biological source consistent with the AP recording**

226

227 A wide diversity of organisms use sound as a method of communication, and particularly in
228 biodiverse areas like Cuba there are many potential natural acoustic sources. Since these
229 incidents were predominantly reported² at night, primarily diurnal sound sources were eliminated
230 from consideration. There might be more than one organism capable of reproducing a sound with
231 the properties of the AP recording. This section explores the rationale for the selection of
232 biological sources that were subjected to additional spectral analysis and comparison with the AP
233 sample.

234

235 **Vertebrates-**

236

237 Frogs: The Caribbean region does have loud frogs such as the Puerto Rican common coqui,
238 *Eleutherodactylus coqui* (Bello and Espinosa 1871), well known for being introduced in Hawaii
239 and apparently depressing property values²⁶ due to their loud advertisement call. Frogs of the
240 genus *Eleutherodactylus* do not produce continuous calls, however, nor do any other amphibians
241 that might be encountered in the Caribbean. The presence of a distinctive pulse repetition rate in
242 the AP recording makes it unlikely a chorus of individual frogs (or other organisms) was
243 responsible.

244

245 Birds: There are no continuously calling nocturnal birds. Additionally, most bird song is of high-
246 complexity to aid in species recognition. Birds are not capable of producing a sustained noise for
247 minutes.

248

249

250 **Insects-**

251 The identification of potential insect sound sources was helped immensely by the website
252 Singing Insects of North America (SINA) <https://entnemdept.ifas.ufl.edu/walker/Buzz>,
253 maintained²² by Thomas J. Walker. Prof. Walker has also conducted extensive work in and
254 published on the calling insects of Caribbean islands. Due to political considerations involving
255 the complicated relationship between the United States and Cuba, there is comparatively little
256 publicly-available data on calling insects of Cuba. This study focused on insects that are present
257 on other Caribbean islands and in Florida in the hope that if a close match were found this would
258 narrow the search for potential Cuban insect sources.

259 There are three primary groups of relevant calling insects: cicadas (superfamily Cicadoidea),
260 katydids or bush crickets (family Tettigoniidae), and various kinds of crickets (superfamily
261 Grylloidea). Many insects (e.g., cicadas, crickets, katydids) communicate acoustically, and
262 exploit both audio and ultrasonic signals. Among these, crickets (one of the most studied models
263 of acoustic communication) exhibit behavioural and biophysical aspects that have fascinated
264 humans for decades.

265

266

267 Cicadas: The Cuban government has implicated²⁷ cicadas as a potential source for the sound
268 heard by U.S. personnel. Unfortunately, little is published about the songs of Cuban cicadas,
269 making detailed spectral analysis difficult. Multiple press reports mention² that the sounds
270 reported by U.S. personnel were heard at night, and cicadas are largely diurnal callers, making it
271 unlikely that they are responsible.

272

273 Katydids: *Neoconocephalus robustus* is the only katydid with a publicly-available recording and
274 an appropriate pulse repetition rate and carrier frequency. Katydids found in the Caribbean
275 typically have²¹ a wider power spectrum than “pure tone” producing crickets. As seen in Figures

276 1 and 3, *N. robustus* has a very different acoustic signature to the AP recording. The largest
277 inconsistency is the lack of a “picket fence” series of lines in the amplitude spectrum. This is an
278 indication of the instability in the PRR of the katydid call. While *N. robustus* is not known to be
279 present on Cuba²⁸ it seemed appropriate to include a katydid exemplar for analysis with a similar
280 carrier frequency and pulse rate as the AP recording, as an illustration of what katydid calls
281 looked like compared to crickets. There are multiple species of *Neoconocephalus* and
282 *Conocephalus* katydids in Cuba. The lack of available audio recordings makes further analysis
283 difficult, however an initial analysis suggests that instability in the PRR is characteristic of North
284 American katydids with recordings uploaded to the SINA²² website.

285
286 Crickets: Male crickets produce three types of signals: 1) Calling songs attract distant females,
287 and are loud, continuous pure-tone calls (with narrow frequency spectrum) peaking between 3-8
288 kHz, depending on the species²². 2) Courtship songs are whisper-like signals of low intensity,
289 given at frequencies higher than calling songs (10-15 kHz). 3) Aggressive or rivalry signals are
290 produced in the presence of other males, usually with broadband spectra²². The calling song
291 informs the female of the male’s presence, its genetic compatibility, and location. Such
292 information is conveyed in the loudness, clarity, directionality, and power spectrum of the call.
293 The calling song’s dominant frequency is often within the human hearing range (50 Hz - 20
294 kHz), and is the call type that is relevant to this research. Crickets are a monophyletic group with
295 multiple subfamilies. After combing through the species accounts of over 130 crickets on the
296 SINA website²², only one species was encountered with a pulse repetition rate matching that of
297 the AP recording. As noted by Walker in his 1973 description of the species, *A. celerinictus* has²⁰
298 the fastest wing stroke rate known for a continuously calling cricket. This turned out to be the
299 best match with the AP recording. Allard, with a delightful turn of phrase, describes²⁹
300 encountering an *Anurogryllus* cricket in the Indies as follows:

301 “In the Dominican Republic when the warm and humid evening arrives,
302 scattered chirping and tinkling notes issue from the shrubs and trees here and there.
303 Some of these are clear, incisive little points of high-pitched sound; others are
304 powerful, penetrating, buzzing, almost ringing noises, continuous and even very
305 disconcerting to many people because of the incessant din.

306 In the Capital city, Ciudad Trujillo, the large brown cricket *Anurogryllus*
307 *muticus* (DeGeer) is very common and noisy throughout the winter. As soon as the
308 night came on and lights appeared, these ubiquitous crickets began their activities
309 out-of-doors in the yard and even within the wide-open houses, for there are no
310 screened windows or doors in the typical Spanish houses.

311 The song of the males of this cricket, here, is a continuous ringing z-z-z-z-z-z- of
312 tremendous volume and penetration which practically fills a room with veritable
313 din. The song is quite like that of our common cone-head, *Neoconocephalus*
314 *robustus crepitans* (Scudder) of the eastern United States. After being accustomed
315 to hear the trilling notes, definitely musical in tonality, of our American
316 individuals of this species, I was somewhat nonplussed to hear this tropical cricket
317 singing continuously, with all the characteristics of a cone-headed katydid, and
318 with no tonality in its stridulation.”

319 **A note on genus *Anurogryllus* including the status of *A. celerinictus* in Cuba:**

320 Publically-available call data exists for only 2 crickets of genus *Anurogryllus* in the Caribbean:
321 *Anurogryllus celerinictus* (Walker 1973) and *Anurogryllus muticus* (De Geer 1773). Prior to
322 1973 the species *A. muticus* was thought to range from the type locality in Suriname through the
323 Eastern United States, but *A. celerinictus* and *A. arboreus* were described²⁰ by Walker in 1973
324 when he split the complex into three species. The primary evidence for this was that crickets
325 previously known as *A. muticus* produced calling songs with three distinctive wingstroke

326 frequencies (or pulse repeat rates in the terminology used here). Walker recorded calls of *A.*
327 *celerinictus* from Jamaica, Grand Cayman, and Big Pine Key. He found that these calls ranged in
328 wingstrokes per second from ~145 Hz at 20 C to ~190 Hz at 28 C with peak carrier frequency
329 ranging from 6-7.4 kHz. Walker reported that *A. muticus* has a peak carrier frequency of 5.8-7.2
330 Hz but only reached a maximum wing stroke rate (PRR) of ~150 Hz at 27 C with a minimum of
331 ~110 Hz at 20 C. *A. arboreus* (Walker 1973) is found only in the mainland U.S. and has a wing
332 stroke rate (PRR) of under 80 Hz. As detailed²⁰ in Walker's 1973 description, *A. celerinictus* and
333 *A. muticus* are not easily distinguishable based on morphology, thus records of *Anurogryllus*
334 crickets listed²⁸ as the earlier described *A. muticus* from Cuba may well include individuals of *A.*
335 *celerinictus*. As there is little published information regarding the calls of Cuban *Anurogryllus*
336 species, it may well be that an individual of another species for which there is no publicly-
337 available call data also produces a similar call. Given the information available and the presence
338 of *A. celerinictus* in the Caymans, Florida Keys, and Jamaica, it seems reasonable to expect that
339 populations previously referred to as *A. muticus* from Cuba might have the *A. celerinictus* call
340 type and therefore be representatives of *A. celerinictus*. Indeed in Walker's description of *A.*
341 *celerinictus* he postulated that the specimens found in the Florida Keys might have recently
342 emigrated from Cuba²⁰ as subsequent trips to the same localities did not produce additional *A.*
343 *celerinictus*. Analysis of the AP recording from Cuba with a higher wingstroke rate than *A.*
344 *muticus* as reported by Walker (1973) provides evidence for the presence of *A. celerinictus* on
345 the island of Cuba.

346

347 Field crickets (Gryllinae) of genus *Gryllus* are well studied, particularly the Jamaican field
348 cricket *Gryllus assimilis*. *G. assimilis* produces calls with a chirp rate^{23,24} of about once per
349 second and most North American biologists (or members of the public) would immediately
350 recognize this call as a cricket. It is unclear why *G. assimilis* was implicated by the Cuban

351 report¹² when the song is readily available via multiple sources online and sounds qualitatively
352 different from the recording released by the AP. A quantitative analysis, shown in Fig. 2,
353 reinforces this conclusion.

354

355 **B. Recordings used in the analysis:**

356 **AP Recording:** An .mp4 file was extracted from the AP's posted³⁰ recording

357 <https://www.youtube.com/watch?v=Nw5MLAu-kKs&feature=youtu.be> using the program

358 FonePaw Video Converter Ultimate version 2.25. The first 0.25 seconds of the AP recording was

359 trimmed as there was no signal. Similarly, the end of the file without signal was trimmed using

360 Audacity 2.2.2 to generate a final .wav file of 5.11 seconds duration. The AP recording was

361 released as both a long format video with additional information⁵, and as a standalone .mp4

362 file³⁰. In the long-format video the AP states that they received multiple similar recordings and

363 that “the U.S. embassy in Havana has played⁵ these recordings for Americans who are working

364 there so they know what to listen to.” The accompanying AP story⁵ asserts that these recordings

365 were received from a U.S. government employee, and were sent to the U.S. Navy for acoustic

366 analysis. The Cuban analysis^{12,27} shows a coarse power spectrum with a 7 kHz peak. This

367 supports the conclusion (in agreement with references¹⁴⁻¹⁶) that the AP released recording is

368 representative of the “sonic attack” recordings in Cuba.

369

370 ***A. celerinictus* field** recording: The recording of *A. celerinictus* was downloaded from the SINA

371 website at <http://entnemdept.ufl.edu/Walker/buzz/492a.htm>. This file is 20 seconds of calling

372 song recorded by T. J. Walker from Big Pine Key, Monroe County, FL. The temperature was 27

373 C at the time of recording. This file is referred to as “*A. celerinictus* field” in the figures and

374 manuscript.

375

376 *A. celerinictus* **echo** recording: This recording was generated by playing the “*A. celerinictus*
377 field” recording on a UE Wonderboom speaker at the base of a stairwell in a house with drywall
378 walls and a tile floor. Other locations indoors in the same tile floored house produce similar
379 results. A recording was also made outdoors to verify the speaker did not introduce distortions or
380 false echoes.

381
382 *Neoconocephalus robustus*: This recording was also downloaded from the website of T. J.
383 Walker at URL <http://entnemdept.ufl.edu/walker/buzz/195a.htm> and is a male from Washington
384 County Ohio calling at 23.8 C.

385
386 *Anurogryllus muticus*: A.L.S. made a series of recordings of *A. muticus* in the Pacific Coast
387 lowlands of Costa Rica in December 2018. Two recordings are presented here as representative
388 of an *Anurogryllus* species recorded away from human structures, Extended Data Audio 2, and
389 from within an open-air restaurant, Extended Data Audio 3. These recordings are illustrative as
390 they show in Extended Data Figure 4 how an echoed recording of an *Anurogryllus* cricket has a
391 obscured pulse structure in comparison to a field recording made away from buildings. A.L.S.
392 also notes that calling *A. muticus* in Costa Rica is loud enough to be the dominant sound even
393 when calling outside noisy restaurants. The only major difference between the call of *A. muticus*
394 and *A. celerinictus* is the higher pulse repetition rate of *A. celerinictus*. To A.L.S. the two calls
395 sound similar, and if both species are on Cuba as they are on Jamaica²⁰ it is possible that U.S.
396 personnel may have heard both species. A release of any additional recordings made by U.S.
397 personnel would clarify this point.

398

399

400 **Analysis methodology**

401

402 **Making Figure 1:**

403 The four audio files described above were each loaded into MATLAB and trimmed to the first 5
404 seconds to match the length of the AP recording. As these audio files were sampled at 44,100
405 samples/second, each 5 second clip has 220,500 data points. The average value of each dataset
406 was subtracted prior to running the MATLAB FFT to obtain an amplitude spectrum, with no
407 window function applied. This produces a spectral bin size of 0.2 Hz. The amplitude spectra
408 were averaged over 25 adjacent data points, to suppress fluctuations, giving an effective spectral
409 resolution of 5 Hz. Each smoothed spectrum was normalized to its peak value. MATLAB
410 program (to be posted online pending publication) Cuba_Figure1.m was used to create the
411 figure.

412

413 **Making Figure 2:** Peak emission frequencies and PRR values were measured either using
414 Audacity version 2.2, or with custom MATLAB code, on downloaded audio files as listed in
415 Supplementary Table 1. Relevant MATLAB programs will be posted online pending publication.

416

417 **Justification for species and associated data plotted in Figure 2:**

418 The recordings available at the SINA website²² were primarily used to determine PRR and peak
419 emission frequency for species of interest. The provenance and results are shown in Extended
420 Data Table 1.

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Making Figure 3:

428 Subsets of 8,192 data points, comprising 0.1858 seconds, of each 5-second recording were
429 sequentially analyzed. The MATLAB FFT function was used to create 5.38 Hz wide spectral
430 bins. Then the MATLAB script Cuba_Figures.m incremented by 4096 data points (half of one
431 sub-segment length) to compute the next FFT, iterating through the entire data file. This means
432 that there is intentional overlap between adjacent subsamples, as a way to smooth the data for
433 visualization. The first of these subspectra was plotted at the top of each waterfall plot. This was
434 scaled to the peak amplitude in the range between 5.5 and 8.5 kHz. The MATLAB program (to
435 be posted online pending publication) Cuba_Figures.m was used to create the figure.

436

Making Figure 4:

438 This figure was created by simply plotting intensity vs. time for each of the three data sets using
439 the same MATLAB program Cuba_Figures.m. This plot starts at 4 seconds into each recording.

440

Making Figure 5:

442 Panels A, B, C are simply different timescale representations of the two recordings. Panel D
443 shows the instantaneous frequency of the signals, measured as Zero Crossing, was obtained with
444 Hilbert transform, using the following MATLAB custom code.

445

hilbert_transform.m

```
447 function[env, phase, inst_freq]=hilbert_transform(signal, Fs)
```

```
448 %Fs = sampling frequency in Hz
```

```
449 signal=signal/max(abs(signal));
```

```
450 signal=signal-mean(signal);
```

451

```
452 hilb=hilbert(signal);
```

```
453 env=abs(hilb);
454 phase=atan2(imag(hilb),real(hilb)) + (pi/2);
455
456 inst_freq=(diff(unwrap(phase))./(1/Fs))./(2*pi);
457 phase=phase*180/pi;
458 phase=modrange(phase, -180, 180);
459 end
460
```

461 **C. Echo detection**

462 If the pulse repetition rate and carrier phase were perfectly stable and the microphone and source
463 were stationary, one would expect echoes to arrive after a constant delay following each pulse.
464 Given the pulse structure evolution seen in Extended Data Figure 1 in the AP sample and the *A.*
465 *celerinictus* “Echo” recording, it appears this is not the case, even for the interior experiment
466 where the source and microphone were stationary.

467
468 Pulse-to-pulse variability evidently induces constructive and destructive interference patterns
469 that vary over time. Adding the field recording to a time-delayed replica reproduces the echo
470 phenomenology. This was verified using Audacity 2.2. With this qualitative understanding of the
471 effect, a quantitative assessment was undertaken. The first step, shown in Extended Data Figure
472 2, was to identify peaks in the recorded sound intensity. The interval between successive peaks
473 was measured using the MATLAB function `findpeaks()` in the script `EchoInterval.m` (available
474 upon publication). Peak detection criteria were:

- 475 • Minimum separation between peaks of 0.5 ms.
- 476 • Minimum peak height of normalized power 0.12.
- 477 • Minimum peak width 0.5 ms.

478

479 As shown in Extended Data Figure 3 the distribution of peak-to-peak intervals is an indicator of
480 echoes and interference. A “short” peak-to-peak time indicates that an echo interrupts the
481 original pulse train. A “long” peak-to-peak time indicates that destructive interference suppresses
482 a peak. In both the AP and *A. celerinictus* “Echo” recordings the fraction of “short” and “long”
483 intervals is similar. This supports the conclusion that the AP recording arises from echoes of a
484 natural source.

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492 **Extended Data Table:**

493

494 **Extended Data Table 1. Full genus and species of all data points in Fig. 2 along with**

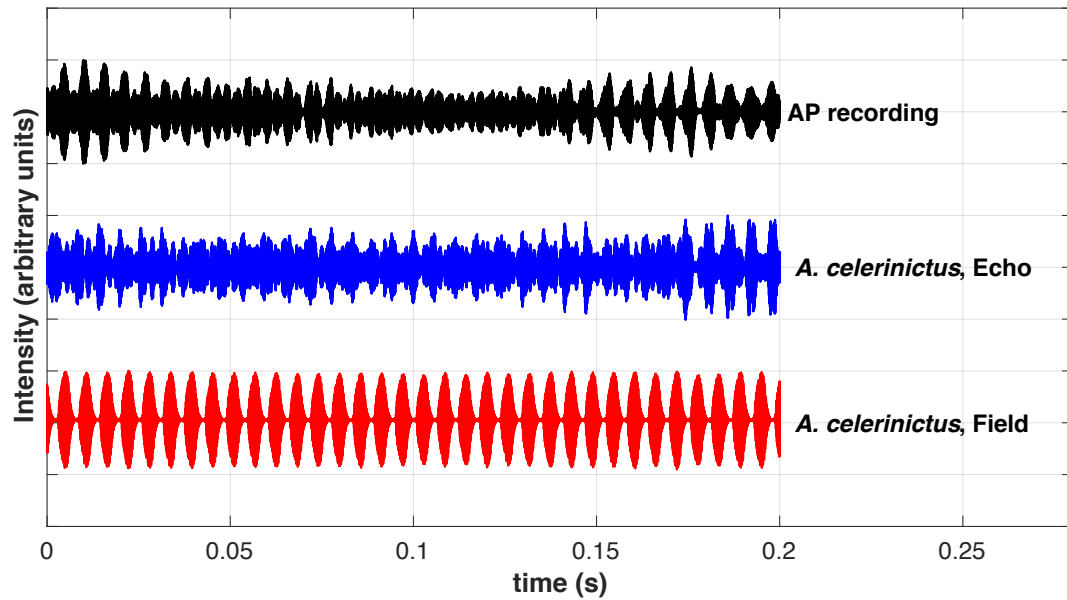
495 **justification for inclusion.**

Species	URL	Rationale
<i>Anurogryllus celerinictus</i>	https://entnemdept.ifas.ufl.edu/walker/buzz/492a.htm	Best match to AP recording
<i>Neoconocephalus robustus</i>	http://entnemdept.ufl.edu/walker/buzz/195a.htm	PRR matches f_{peak} matches PRR stability does not match Call is much more broadband than AP recording No evidence for being found on Cuba
<i>Conocephalus fasciatus</i>	http://entnemdept.ufl.edu/walker/buzz/231a.htm	Katydid known to inhabit Cuba
<i>Oecanthus celerinictus</i>	http://entnemdept.ufl.edu/walker/buzz/583a.htm	Fastest calling tree cricket, high PRR
<i>Conocephalus cinereus</i>	http://entomology.ifas.ufl.edu/walker/buzz/232a.htm	Katydid known to inhabit Cuba
<i>Gryllus assimilis</i>	http://entomology.ifas.ufl.edu/walker/buzz/483a.htm	Proposed by Cubans as natural source
<i>Anurogryllus arboreus</i>	http://entomology.ifas.ufl.edu/walker/buzz/491a.htm	Related to <i>A. celerinictus</i>

<i>Neoconocephalus carbonarius</i>	https://macaulaylibrary.org/asset/131991	Fast-calling katydid, intermittent call.
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Extended Data Figures:



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500

501 **Extended Data Figure 1. Expanded pulse structure comparison.** This shows a longer time
502 series for all three recordings of interest. The red *A. celerinictus* Field recording converts into the
503 blue Echo trace when played indoors, which strongly resembles the AP recording. In the AP
504 recording there are regions of high pulse amplitude at 0.01 and 0.17 seconds in this plot
505 bounding a region of low pulse amplitude at 0.11 seconds. This seemingly symmetrical pattern
506 suggested interfering waves moving in and out of phase.

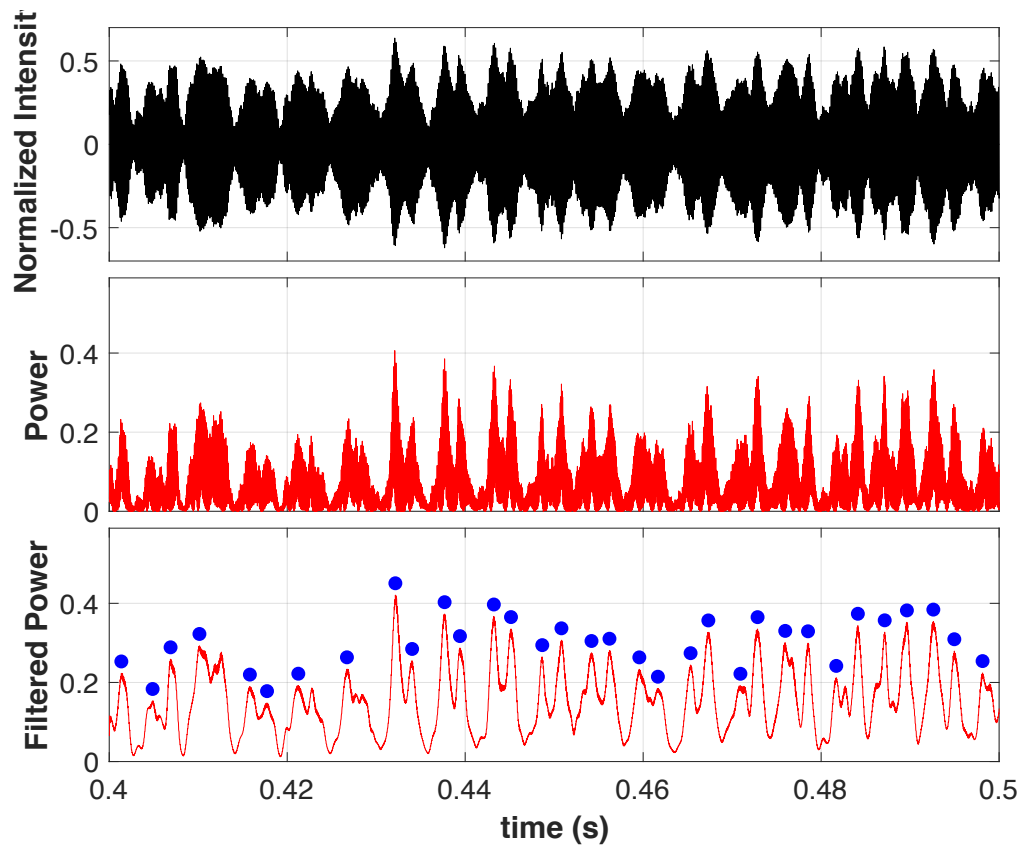
507
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515 **Extended Data Figure 2. Pulse interval determination.** The upper panel shows intensity vs.

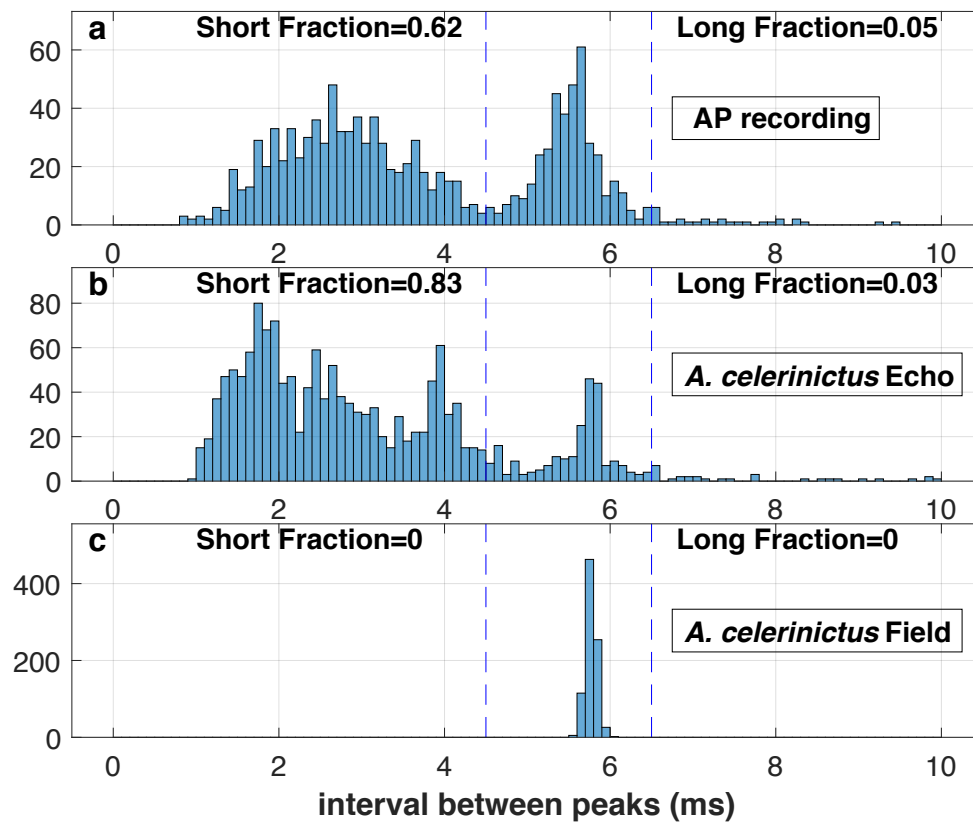
516 time from the AP recording, the middle panel shows power (intensity squared), the lower panel

517 shows a low-pass filtered version of the power vs. time. This allows for automated peak

518 detection (shown as blue dots), from which the interval between peaks can be determined.

519

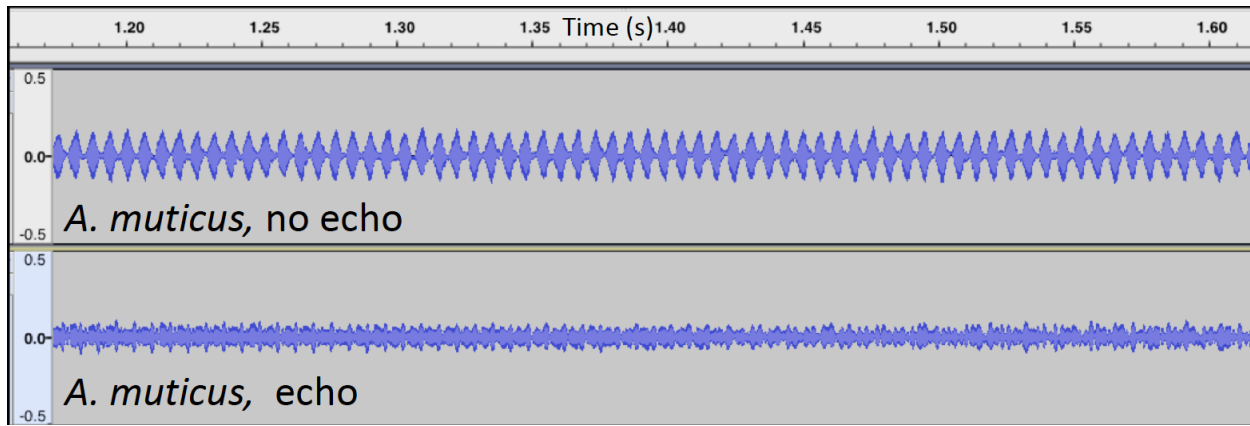
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524 **Extended Data Figure 3. Peak interval histograms.** **c**, In the Field recording the interval
525 between two successive peaks is constant at just under 6 ms, the reciprocal of the PRR. **b**, A
526 significant fraction (0.83) of “interloper” peaks from the echo produce short intervals. Also, ~3%
527 of the time destructive interference suppresses adjacent peaks. **a**, Similar interval statistics
528 occur in the AP recording. **a-c**, The vertical dashed lines define short and long fractions
529 respectively.

530



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534 **Extended Data Figure 4. Recording of related *Anurogryllus muticus* from Costa Rica with**

535 **and without echoes.** The top panel shows a recording of *A. muticus* taken in a palm grove
536 away from structures that might produce echoes. The bottom panel is a recording of the same
537 species made approximately 2 meters away from a concrete wall inside a restaurant in Costa
538 Rica. This shows a real-world example of how recordings near structure obscure the pulse
539 structure of *Anurogryllus* calls.

540
541

542 **Extended Data Audio 1. Echoed recording of *A. celerinictus*.** This 5 second audio clip was
543 obtained by replaying the field recording indoors.

544

545 **Extended Data Audio 2. Field recording of *Anurogryllus muticus* from Costa Rica without**
546 **echoes.** This recording was made in a stand of coconut palms away from any buildings and
547 therefore is without echoes. This pulse structure looks very similar to the *A. celerinictus* “field”
548 recording in pulse structure, though the pulse repetition rate is slower.

549

550 **Extended Data Audio 3. Field recording of *A. muticus* from Costa Rica made near a cement**
551 **wall.** This recording was made inside a restaurant in Costa Rica, where a cricket was calling just

552 outside adjacent a cement wall. Here there are considerable echoes that impact the pulse

553 structure, in much the same way as the AP recording.

554

555

556

557 **References**

558

559 1. Stone, R. Reports of inner-ear damage deepen diplomat controversy. *Science* **360.6395**,
560 1281-1282 (2018). <https://doi.org/10.1126/science.360.6395.1281>

561

562 2. Golden, T. & Rotella S. The sound and the fury: Inside the mystery of the Havana
563 Embassy. ProPublica (14 February 2018). [https://www.propublica.org/article/diplomats-](https://www.propublica.org/article/diplomats-in-cuba)
564 [in-cuba](https://www.propublica.org/article/diplomats-in-cuba)

565

566 3. Toosi, N. “U.S. limits diplomatic tours in Cuba following mysterious illnesses” (Politico,
567 15 August 2018). [https://www.politico.com/story/2018/08/15/us-cuba-diplomats-sonic-](https://www.politico.com/story/2018/08/15/us-cuba-diplomats-sonic-attacks-778355)
568 [attacks-778355](https://www.politico.com/story/2018/08/15/us-cuba-diplomats-sonic-attacks-778355)

569

570 4. Swanson, R. L. 2nd *et al.* Neurological manifestations among US government personnel
571 reporting directional audible and sensory phenomena in Havana, Cuba. *JAMA* **319.11**,
572 1125–1133 (2018). <https://doi.org/10.1001/jama.2018.1742>

573

574 5. Lederman, J. & Weissenstein, M. “Dangerous sound? What Americans heard in Cuba
575 attacks” (AP News, 13 October 2017).
576 <https://www.apnews.com/88bb914f8b284088bce48e54f6736d84>

577

578 6. Della Sala, S. & Cubelli, R. Alleged “sonic attack” supported by poor neuropsychology.
579 *Cortex* **103** (2018). <https://doi.org/10.1016/j.cortex.2018.03.006>

580

- 581 7. Della Sala, S. & McIntosh, R. D. Cognitive impairments that everybody has. *J. Neurol.*
582 **265.7**, 1706-1707 (2018). <https://doi.org/10.1007/s00415-018-8914-8>
583
- 584 8. Shura, R. D., Kacmarski, J. A. & Miskey, H. M. Neurological Symptoms in US
585 Government Personnel in Cuba. *JAMA*. **320.6**, 603 (2018).
586 <https://doi.org/10.1001/jama.2018.8698>
587
- 588 9. Bartholomew, R. E. Neurological Symptoms in US Government Personnel in
589 Cuba. *JAMA*. **320.6**, 602 (2018). <https://doi.org/10.1001/jama.2018.8702>
590
- 591 10. Bartholomew, R. E. & Pérez, D. Z. Chasing ghosts in Cuba: Is mass psychogenic illness
592 masquerading as an acoustical attack? *Int. J. Soc. Psychiatry* **64**, 413-416 (2018).
593 <https://doi.org/10.1177/0020764018766185>
594
- 595 11. Stone, J., Popkirov, S. & Carson, A. J. Neurological Symptoms in US Government
596 Personnel in Cuba. *JAMA* **320.6**, 602-603 (2018). <https://doi.org/10.1001/jama.2018.8706>
597
- 598 12. Barcelo-Pérez, C. & González Sánchez, Y. Non usual urban sounds in a Western
599 Neighborhood of Havana City (2018). <https://doi.org/10.13140/RG.2.2.13026.43205>
600
- 601 13. Lin, J. C. Strange Reports of Weaponized Sound in Cuba [Health Matters], *IEEE*
602 *Microw. Mag.* **19.1**, 18-19 (2018). <https://doi.org/10.1109/MMM.2017.2765778>
603
- 604 14. Yan, C., Fu, K. & Xu, W. “On Cuba, diplomats, ultrasound, and intermodulation
605 distortion” (Tech. Rep. CSE-TR-001-18, U. Mich., 2018)

606

607 15. Fu, K., Xu, W. & Yan, C. How we reverse engineered the Cuban “sonic weapon” attack.

608 *IEEE Spectr.* (15 March 2018). [https://spectrum.ieee.org/semiconductors/devices/how-](https://spectrum.ieee.org/semiconductors/devices/how-we-reverse-engineered-the-cuban-sonic-weapon-attack)

609 [we-reverse-engineered-the-cuban-sonic-weapon-attack](https://spectrum.ieee.org/semiconductors/devices/how-we-reverse-engineered-the-cuban-sonic-weapon-attack)

610

611 16. Fu, K. & Xu, W. Can sound be used as a weapon? 4 questions answered, *The*

612 *Conversation* (1 March 2018). [https://theconversation.com/can-sound-be-used-as-a-](https://theconversation.com/can-sound-be-used-as-a-weapon-4-questions-answered-83627)

613 [weapon-4-questions-answered-83627](https://theconversation.com/can-sound-be-used-as-a-weapon-4-questions-answered-83627)

614

615 17. Bennet-Clark, H. C. Resonators in insect sound production: how insects produce loud

616 pure-tone songs. *J. Exp. Biol.* **202.23**, 3347-3357 (1999)

617

618 18. Chivers, B. D., Jonsson, T., Soulsbury, C. D. & Montealegre-Z., F. Structural

619 biomechanics determine spectral purity of bush-cricket calls. *Biol. Lett.* **13.11** (2017).

620 <https://doi.org/10.1098/rsbl.2017.0573>

621

622 19. Potamitis, I., Ganchev, T. & Fakotakis, N. “Automatic acoustic identification of crickets

623 and cicadas,” *2007 9th International Symposium on Signal Processing and Its*

624 *Applications. ISSPA 2007. IEEE*, 1-4 (2007).

625 <https://doi.org/10.1109/ISSPA.2007.4555462>

626

627 20. Walker, T. J. Systematics and acoustic behavior of United States and Caribbean short-

628 tailed crickets (Orthoptera: Gryllidae: Anurogryllus). *Ann. Entomol. Soc. Am.* **66.6**, 1269-

629 1277 (1973). <https://doi.org/10.1093/aesa/66.6.1269>

630

- 631 21. Walker, T. J. & Greenfield, M. D. Songs and Systematics of Caribbean Neoconocephalus
632 (Orthoptera: Tettigoniidae). *T. Am. Entomol. Soc. (1890-)* **109.4**, 357–389 (1983).
633 JSTOR, <http://www.jstor.org/stable/25078329>
- 634
- 635 22. Walker, T. J. “Singing insects of North America (SINA)”;
636 <http://entnemdept.ufl.edu/Walker/buzz/> [accessed 17 August 2018]
637
- 638 23. Weissman, D. B., Walker, T. J. & Gray, D. A. The field cricket *Gryllus assimilis* and two
639 new sister species (Orthoptera: Gryllidae). *Ann. Entomol. Soc. Am.* **102.3**, 367-380
640 (2009). <https://doi.org/10.1603/008.102.0304>
641
- 642 24. Pollack, G. & Kim, J. S. Selective phonotaxis to high sound-pulse rate in the cricket
643 *Gryllus assimilis*. *J. Comp. Physiol. A Neuroethol. Sens. Neural. Behav. Physiol.* **199**,
644 (2013). <https://doi.org/10.1007/s00359-013-0792-z>
645
- 646 25. “Mystery of sonic weapon attacks at US embassy in Cuba deepens” (Associated Press, 14
647 [September 2017](https://www.theguardian.com/world/2017/sep/14/mystery-of-sonic-weapon-attacks-at-us-embassy-in-cuba-deepens)). [https://www.theguardian.com/world/2017/sep/14/mystery-of-sonic-](https://www.theguardian.com/world/2017/sep/14/mystery-of-sonic-weapon-attacks-at-us-embassy-in-cuba-deepens)
648 [weapon-attacks-at-us-embassy-in-cuba-deepens](https://www.theguardian.com/world/2017/sep/14/mystery-of-sonic-weapon-attacks-at-us-embassy-in-cuba-deepens)
649
- 650 26. Kaiser, B. A. & Burnett, K. M. Economic impacts of *E. coqui* frogs in Hawaii. *IER* **8.2**,
651 1-11 (2006). <https://doi.org/10.1504/IER.2006.053951>
652

- 653 27. “Alleged sonic attacks” (Granma: Official Voice of the Communist Party of Cuba Central
654 Committee, 27 October 2017). [http://en.granma.cu/cuba/2017-10-27/alleged-sonic-](http://en.granma.cu/cuba/2017-10-27/alleged-sonic-attacks)
655 [attacks](http://en.granma.cu/cuba/2017-10-27/alleged-sonic-attacks)
656
- 657 28. Yong, S. & Perez-Gelabert, D. Grasshoppers, crickets and katydids (Insecta: Orthoptera)
658 of Cuba: An annotated checklist. *Zootaxa* **3827.4**, 401-438 (2014).
659 <https://doi.org/10.11646/zootaxa.3827.4.1>
660
- 661 29. Allard, H. A. The stridulations of some crickets in the Dominican Republic. *J. Wash.*
662 *Acad. Sci.* **47.5**, 150-152 (1957).
663 <https://www.biodiversitylibrary.org/part/101726#/summary>
664
- 665 30. “Dangerous sound? A recording of what some U.S. Embassy workers heard in Havana”
666 (AP Digital Products, 12 October 2017).
667 <https://www.youtube.com/watch?v=Nw5MLAu-kKs&feature=youtu.be>
668
- 669 31. Prestwich, K. N., Lenihan, K. M. & Martin, D. M. The control of carrier frequency in
670 cricket calls: A refutation of the subalar-tegmina resonance/auditory feedback model. *J.*
671 *Exp. Biol.* **203**, 585-596 (2000).
672
- 673 32. Kutsch, W. Neuromuscular activity in 3 cricket species during various behavioural
674 patterns. *Zeitschrift Fur Vergleichende Physiologie* **63**, 335-& (1969).
675

676 33. Montealegre-Z, F., Jonsson, T. & Robert, D. Sound radiation and wing mechanics in
677 stridulating field crickets (Orthoptera: Gryllidae). *J. Exp. Biol.* **214**, (2011).
678 doi:10.1242/jeb.056283

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681 **Supplementary information line**

682 Extended Data Table 1

683 Extended Data Figs. 1-4

684 Extended Data Audio 1-3

685 Caption for Extended Data Audio 1-3

686

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694

695

696 **Competing interests**

697 The authors declare no competing interests.

698

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700

701 **Data Disposition**

702 All recordings used for analysis except for the the three supplementary audio recordings are
703 publicly available. The “*A. celerinictus* echo” recording is available as “Extended Data Audio 1
704 echoed_celerinictus.wav” while the *A. muticus* echo and *A. muticus* field are available as
705 Extendeddataaudio1.mpg and Extendeddataaudio2.

706 All code used for spectral analysis and to make the figures will be uploaded to github upon
707 publication. The data used to generate Figure 2 is part of this code.

708