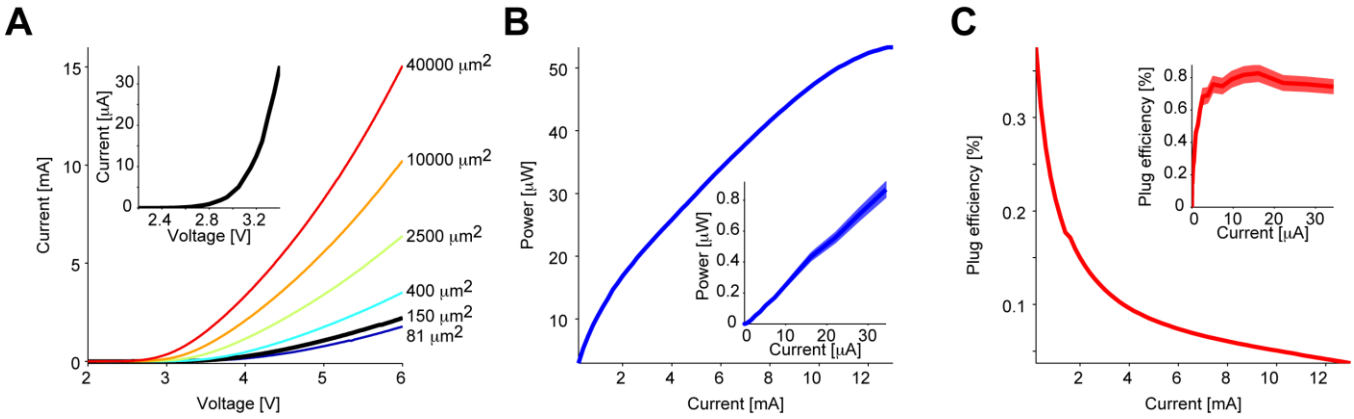

Figure S1. Full range characterization of the LEDs, related to Figure 3. (**A**) Current versus voltage characteristics of various LED sizes (inset correspond to the low-bias characterization of the 150-μm^2 LED used in the actual μLED probes, cf. **Figure 3A**). (**B**) Current versus power. (**C**) Current versus plug efficiency.

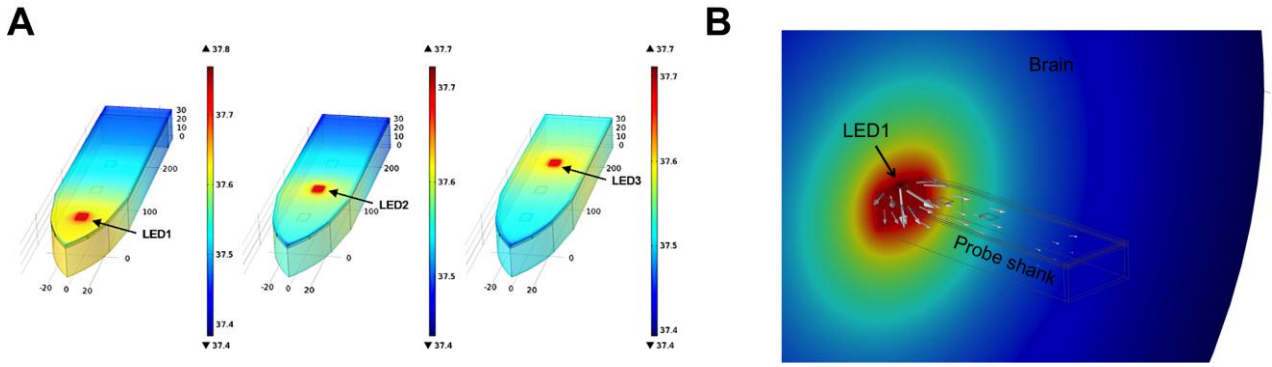

Figure S2. COMSOL thermal modeling during LED operations, related to Figure 3. (**A**) Temperature rise is highest at the surface of LED1 as compared to LED2 and LED3 at any given input bias. (**B**) Cross-section of the probe and the surrounding brain tissue (centered at LED1) shows near concentric temperature profile. White arrows show heat flux at logarithmic scale, indicating that the thermal energy preferentially dissipates through the conductive silicon shank rather than escaping into the brain tissue.

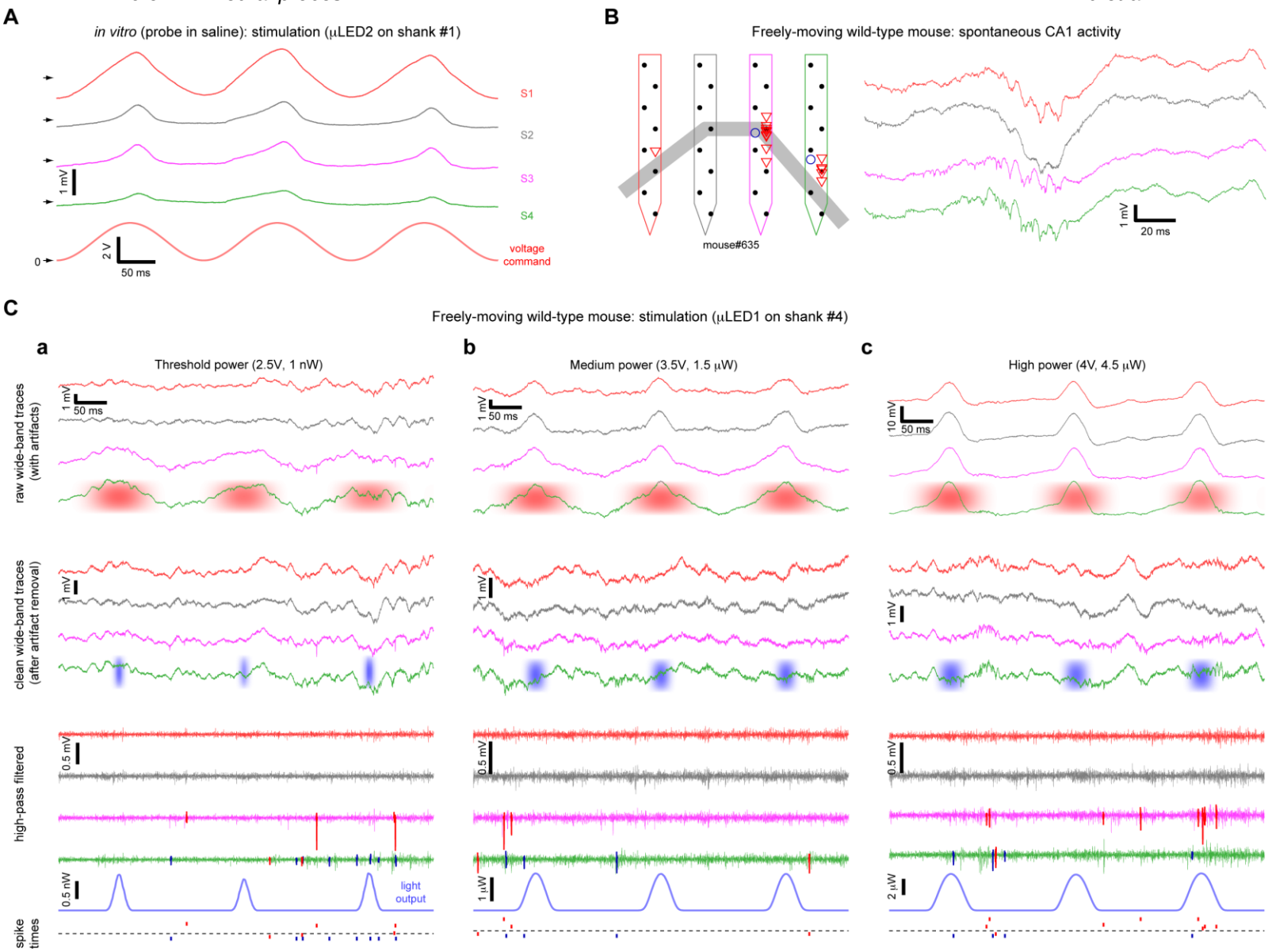

Figure S3. μLED probe illumination does not induce spiking or iHFOs in wild-type mice, related to Figure 4. (**A**) μLED probe illumination induces artifacts in saline. A voltage command of 3.5V was used to drive μLED2 on shank #1. The interference on shank #1 has a sinusoidal (voltage) waveform (putatively arising from the adjacent recording site and LED signal traces on the PCB), whereas the interference on the other shanks has a superimposed rectified (current) waveform (putatively due to capacitive coupling between the n-GaN layer and the recording sites on the probe). No fast artifacts are evident. (**B**) Example wide-band traces from the center of the CA1 pyramidal cell layer of wild-type mouse during open-field foraging. Left: gray line: estimated location of the layer (peak ripple power); blue circles: estimated location of interneuron somata; red triangles: pyramidal cells (PYR). (**C**) Artifacts in the freely-moving mouse are similar to those induced in saline and can be removed by cycle-triggered subtraction. (**a**) Recording from the same sites (in the same wild-type mouse) during 3 cycles of minimal stimulation on the central μLED on shank 4 (5 Hz sine wave, 2.5V bias; red blobs); the resulting current/light waveform is also shown (peak power, 1 nW; blue blobs and light blue trace). (**top**) Although no spiking was modulated and no iHFOs were induced, a low-frequency time-locked artifact, reminiscent of voltage trace ("PCB-mediated"), is apparent on the same shank as the μLED. (**middle**) This artifact was removed by triggering, averaging, and subtracting, for each neuronal channel separately, resulting in "cleaned" traces. (**bottom**) Spike timing was not modulated (via e.g. ephaptic coupling) by the diode current. (**b**) Similar analysis during supra-threshold light (1.5 μW) – a level sufficient, in CaMKII::ChR2 animals, for inducing spiking but not robust iHFOs (**Figure 4; Figure S5; Figure 6**). Here the artifacts are composite, influenced by both the voltage

("PCB-mediated") and current ("probe-mediated"). In this case as well, artifacts were completely removed by cycle-triggered subtraction. (**c**) Similar analysis during high power (4.5 μW) stimulation. In all cases, artifacts were completely removed by cycle-triggered subtraction. In no cases were spikes or iHFOs generated; similar results were observed in two wild-type mice (#635 and #636).

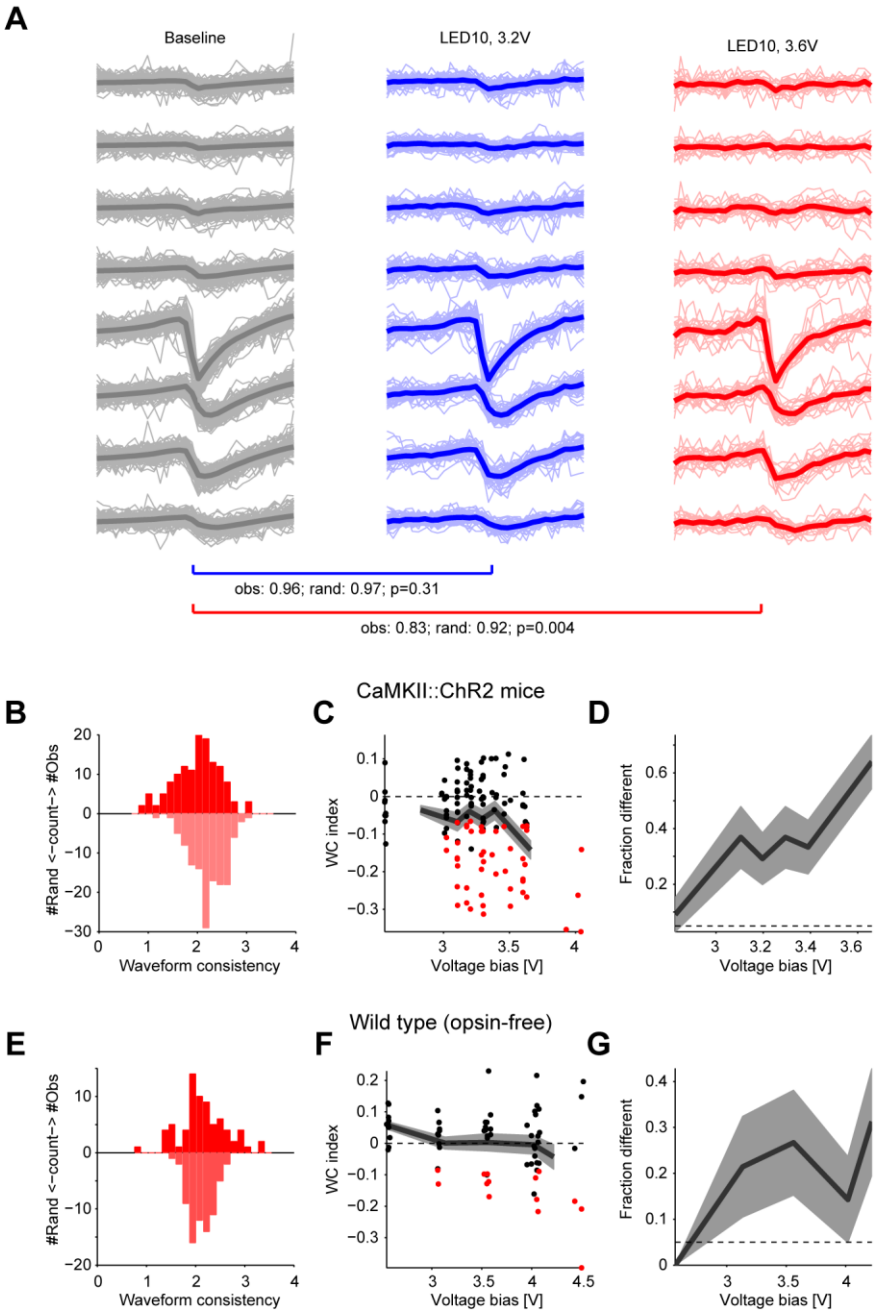

Figure S4. High but not low power light distorts extracellularly recorded spike waveforms, related to Figure 4. (**A**) Example waveforms (same unit as shown in **Figure 4**, pink). The "Baseline" condition includes 14,427 spikes; the 3.2V condition includes 54 spikes (same data as used in **Figure 4C**, bottom left); and the 3.6V condition includes 22 spikes. The correlation coefficient between the waveforms during baseline and 3.2V (330 µW) is 0.96, and the correlation for randomized labels is similar (p=0.31, permutation test). For the 3.6V (1.7 µW), the correlation drops to 0.83 (p=0.004), indicating distortion. (**B-G**) High power light distorts waveforms. **B**. Waveform consistency (Fisher z-transform of the correlation coefficient) for the entire dataset (top: observed; bottom: randomized, i.e. with shuffled labels). **C**. Waveform consistency index (observed minus randomized, divided by the sum) plotted against voltage bias. Band shows mean and s.e.m. at 6 equally-populated voltage bins. **D**. Fraction of significantly-distorted (alpha level, 0.05) PYR plotted against voltage bias. Distortion is more frequent and larger when voltage bias is increased. Overall, in 47/133 cases (35%), spike waveforms were distorted between baseline and light conditions (p<0.05, permutation test). (**E-G**) Similar analysis in control (opsin-free) mice. In 14/72 (19%), waveforms were distorted.

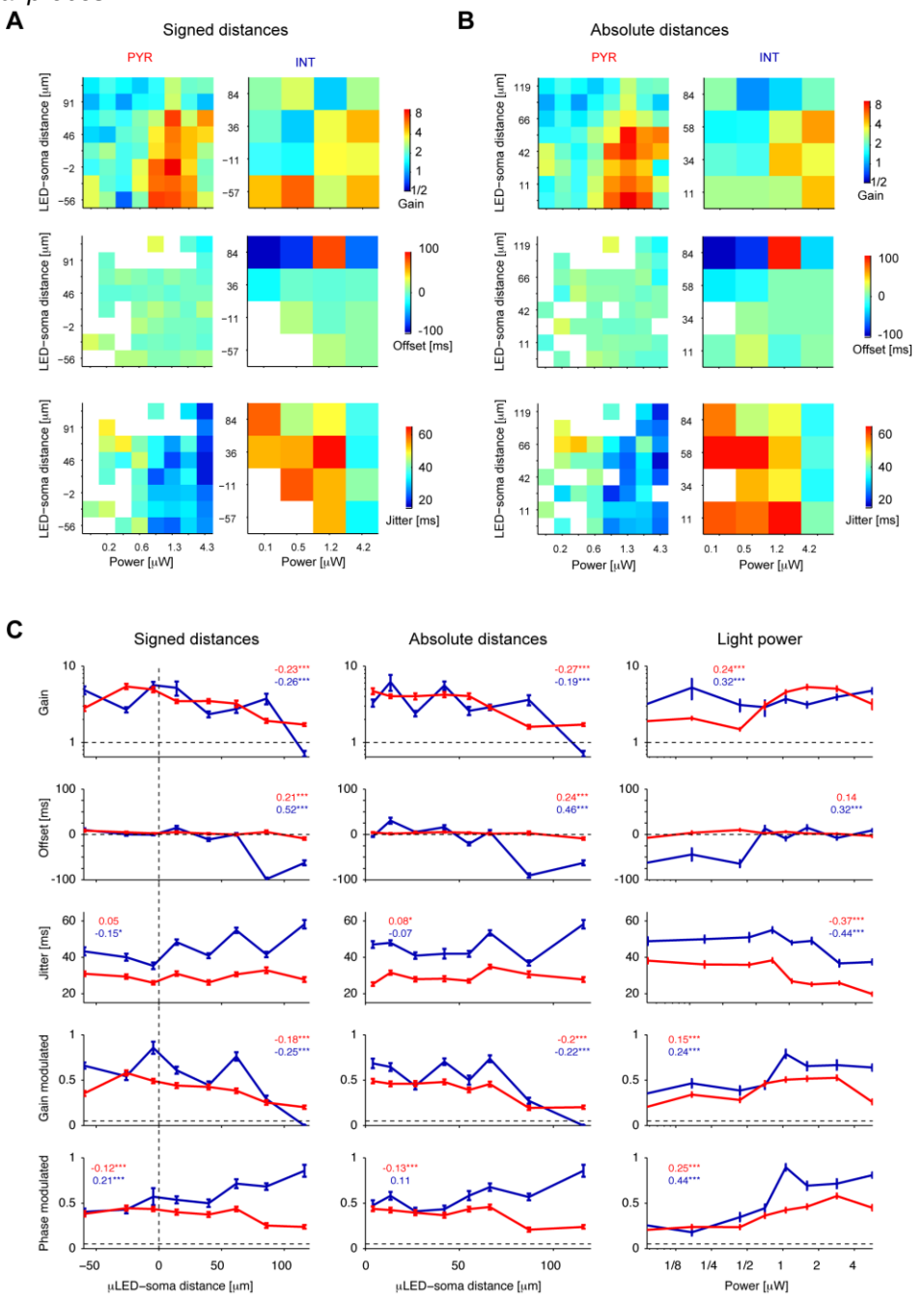

Figure S5. Local and non-local spiking during µLED illumination, related to Figure 4. (**A**) Dependence of spiking gain (top), spike timing offset (center), and temporal jitter (bottom) for 38 PYR (left) and 11 interneurons (INT; right). Binning was done such that the number of data points per bin in the marginal distributions is approximately equal (INT: 235 data points, 11-20 points/bin, median: 15; PYR: 690 data points, 5-18 points/bin, median: 11). For the offset/jitter panels, only distance-power bins in which the number of time-locked units exceeds chance ($p<0.05$, Binomial test) are shown. Identical matrices are in main **Figure 4D** and **5B**. (**B**) Similar analysis in which distance binning was done according to the absolute µLED-soma distances. (**C**) Marginal distributions of the same three dependent variables (gain, offset, and jitter) as in **A** and **B** as well as the probability to see gain- (increased; $p<0.05$, Poisson test) or phase-modulated (time-locked; $p<0.05$, permutation test) spiking. Independent variables (µLED-soma distance and power) are uncorrelated (0.002, $p=0.94$). Numbers indicate rank correlation coefficients (or, for the offset plots, circular-linear correlation coefficients); */***, $p<0.05/0.005$, permutation test, 1000 randomizations.

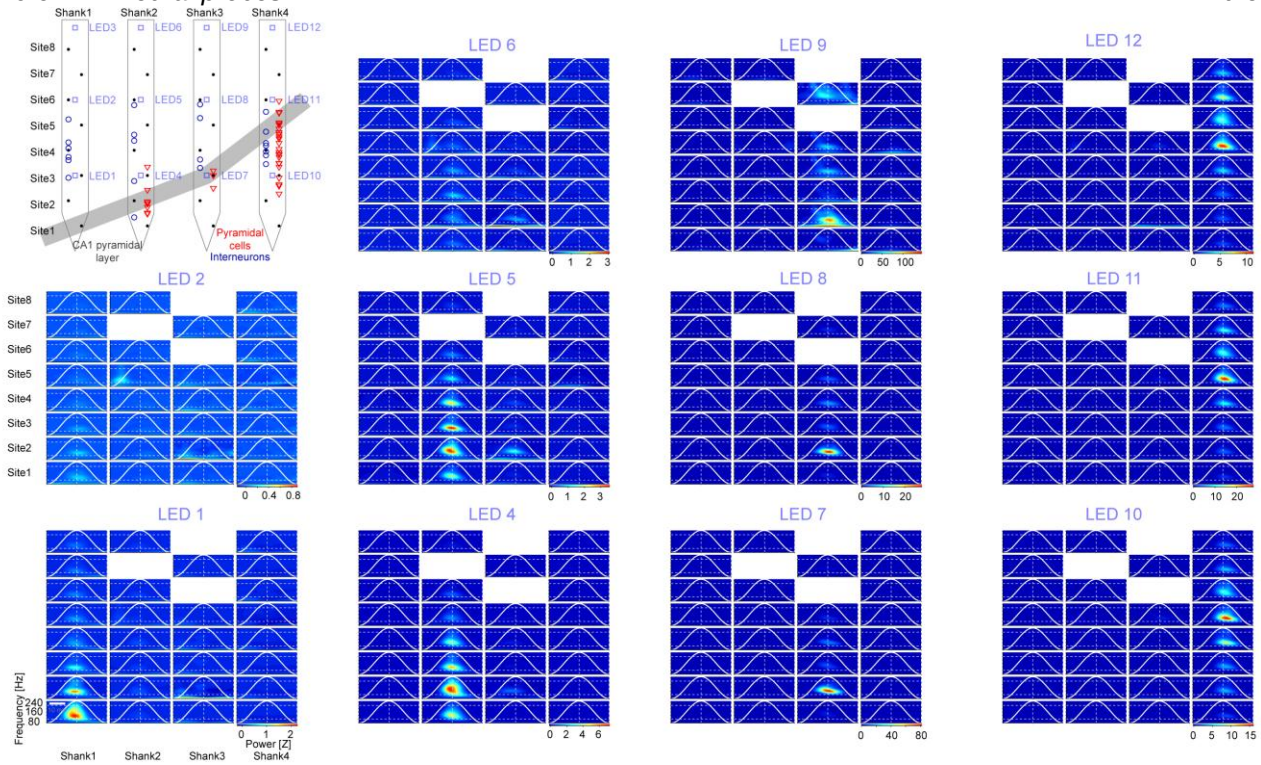

Figure S6. Example multi-site iHFOs, related to Figure 6. Data includes recordings from 29 (out of 32) sites, during stimulation by 11 (out of 12) µLEDs. Schematic (top left) shows the estimated locations of neuronal somata (red triangles and blue circles) and the estimated location of the center of the CA1 pyramidal layer (gray line, sites of peak ripple power). Each panel shows the time-frequency decomposition of one channel during single-µLED illumination; in this example, all µLEDs were activated n=30 times at 4.2 µW. Color code is the same for each µLED but defined separately for different µLEDs. The frequency, locus, spatial dispersion, and in this case also the power of the induced HFOs, all depend on the illumination site. In particular, illumination close to the center of the CA1 pyramidal layer generates iHFOs of higher frequency which are more compact spatially, whereas distant illumination shifts the sites of the iHFOs.

Movie S1. Example of 12 μLEDs driven independently at 3 V bias, related to Figure 2. The controller is programmed using LabVIEW (National Instruments).