LETTER

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Anthropogenic electromagnetic noise disrupts magnetic compass orientation in a migratory bird

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gatsby tea talk
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- night-migratory song-birds can use Earth’s magnetic field to orient spontaneously, when placed in an “orientation cage” at night in spring and autumn
- BUT night-migratory song-birds tested between autumn 2004 and autumn 2006 in wooden huts on the University of Oldenburg campus (53.1507° N, 8.1648° E) seemed unable to orient
- ?????

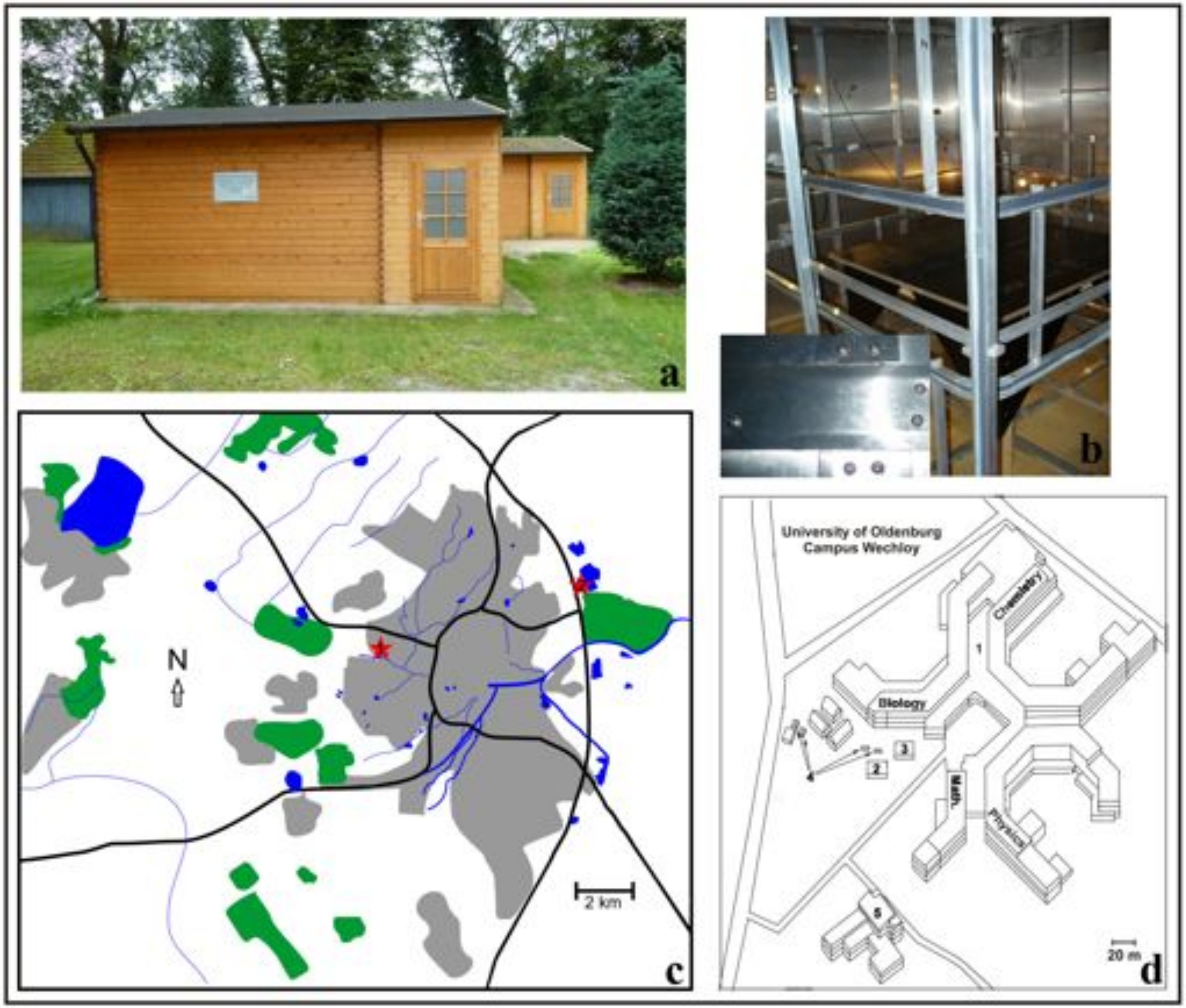
- maybe birds are sensitive to EM noise (anthropogenic electromagnetic radiation)???
- at levels "well below the guidelines for human exposure proposed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and adopted by the World Health Organization"

- BUT
  - such claims in the past have often proved difficult to reproduce
  - animal studies were already used for guidelines
  - "seemingly implausible effects require stronger proof"

experimental setup

european robin

orientation cage



Extended Data Figure 1 | Wooden huts and experimental locations. **a**, Photograph of one of the four identical wooden huts used for our experiments. **b**, Photograph from the inside of an experimental hut showing the aluminium screening, parts of the Merritt coil system, and the table on which the funnels were placed. The insert shows the self-cutting screws used to connect the aluminium plates. **c**, Simple map of the city of Oldenburg. Built-up areas are shown in grey and nature-protected areas in green. Black lines denote highways, blue denotes water. Red stars: '1' indicates the location of the University campus and '2' the rural location used for some of the tests. **d**, Map of the University of Oldenburg Wechloy Campus. 1, main University building housing the biology, chemistry, physics and mathematics institutes; 2, botanical greenhouse; 3, iron-free wooden building; 4, the locations of the four wooden huts used for our experiments; 5, 'Next Energy' building.

migratory European robins orient towards magnetic north

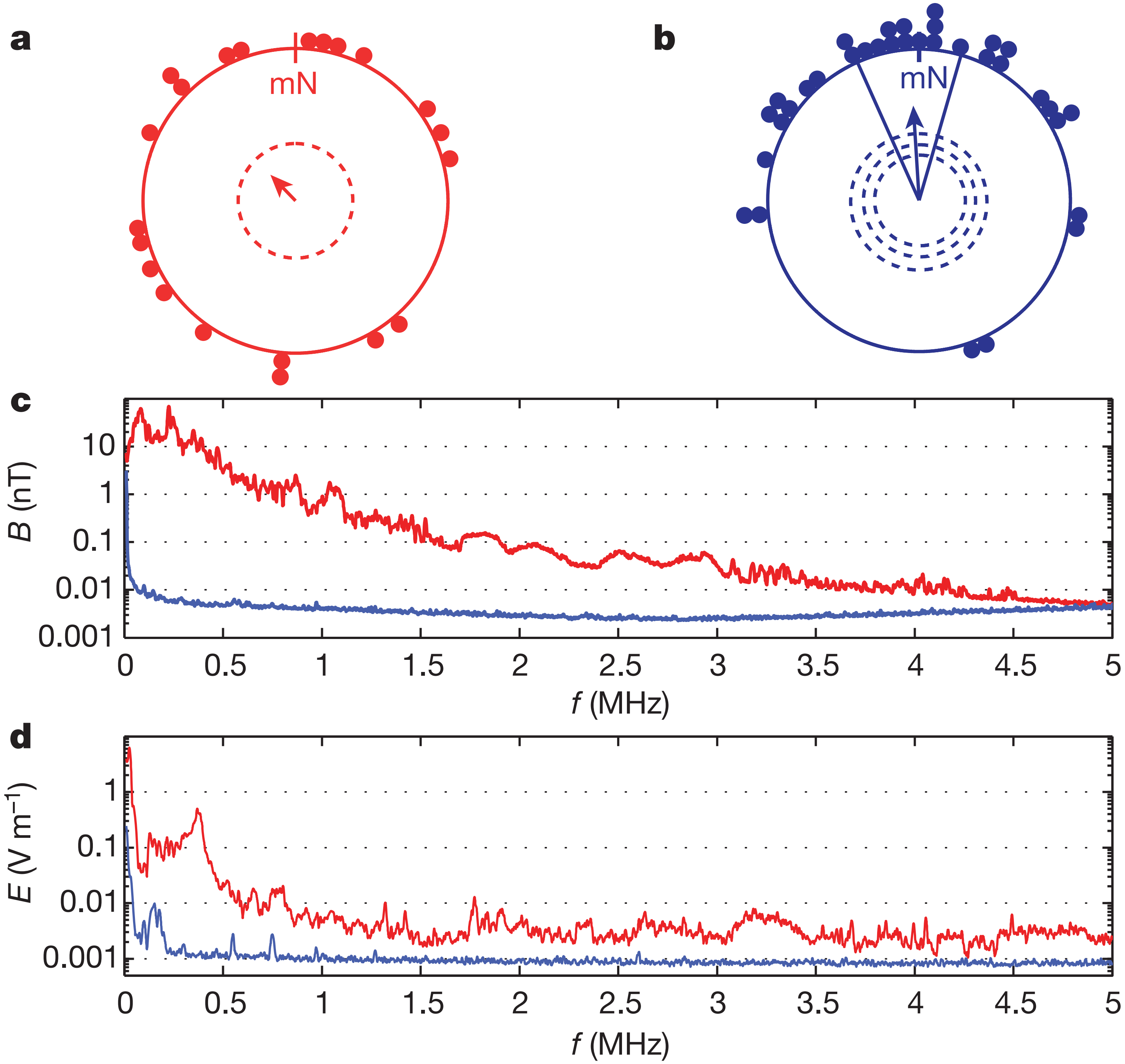
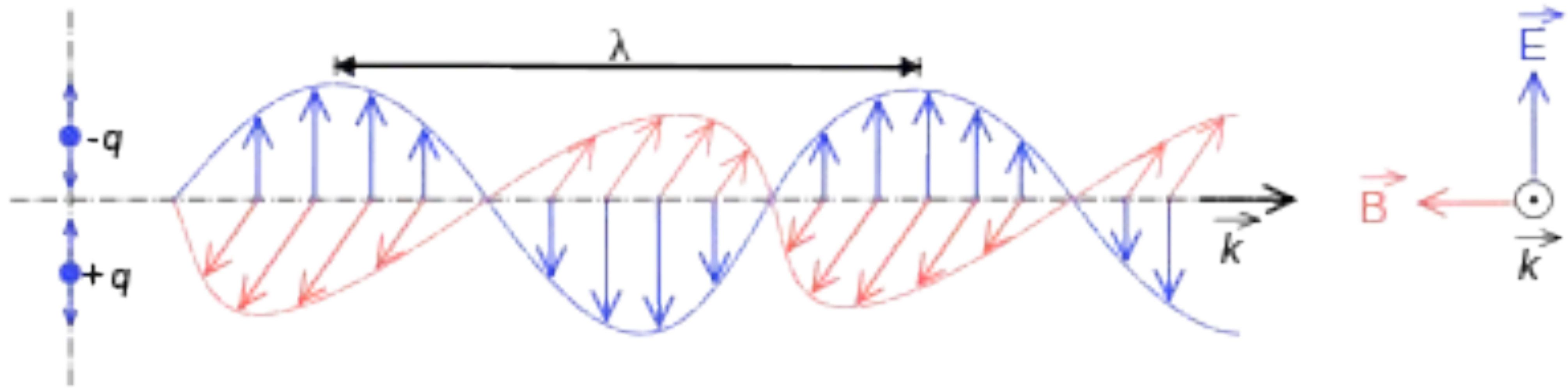


Figure 1 | Magnetic compass orientation of migratory European robins tested at the University of Oldenburg requires aluminium screening. In unscreened wooden huts, European robins were disoriented (**a**, spring 2005, $n = 21$, mean direction 316°, mean vector length $r = 0.19$, $P = 0.48$ (Rayleigh test)), but after installing grounded aluminium screens, the birds oriented highly significantly towards North in spring (**b**, spring 2007, $n = 34$, mean direction 356° ± 20° (95% confidence interval), $r = 0.59$, $P < 0.001$). **c**, **d**, Anthropogenic electromagnetic noise in the huts before (red) and after (blue) installation of screens. Traces **c** and **d** show the magnetic (B) and electric (E) components of the measured electromagnetic fields, respectively, as a function of frequency (f). In **a**, **b**, each dot indicates the mean orientation of all the tests of one individual bird in the given condition. The dots are colour-coded as in **c**, **d**. The arrows show group mean vectors flanked by their 95% confidence interval limits (solid lines). The dashed circles indicate the minimum length of the group mean vector needed for significance according to the Rayleigh test (inner circle, $P = 0.05$; middle, $P = 0.01$; outer, $P = 0.001$). mN, magnetic North.

electromagnetic radiation

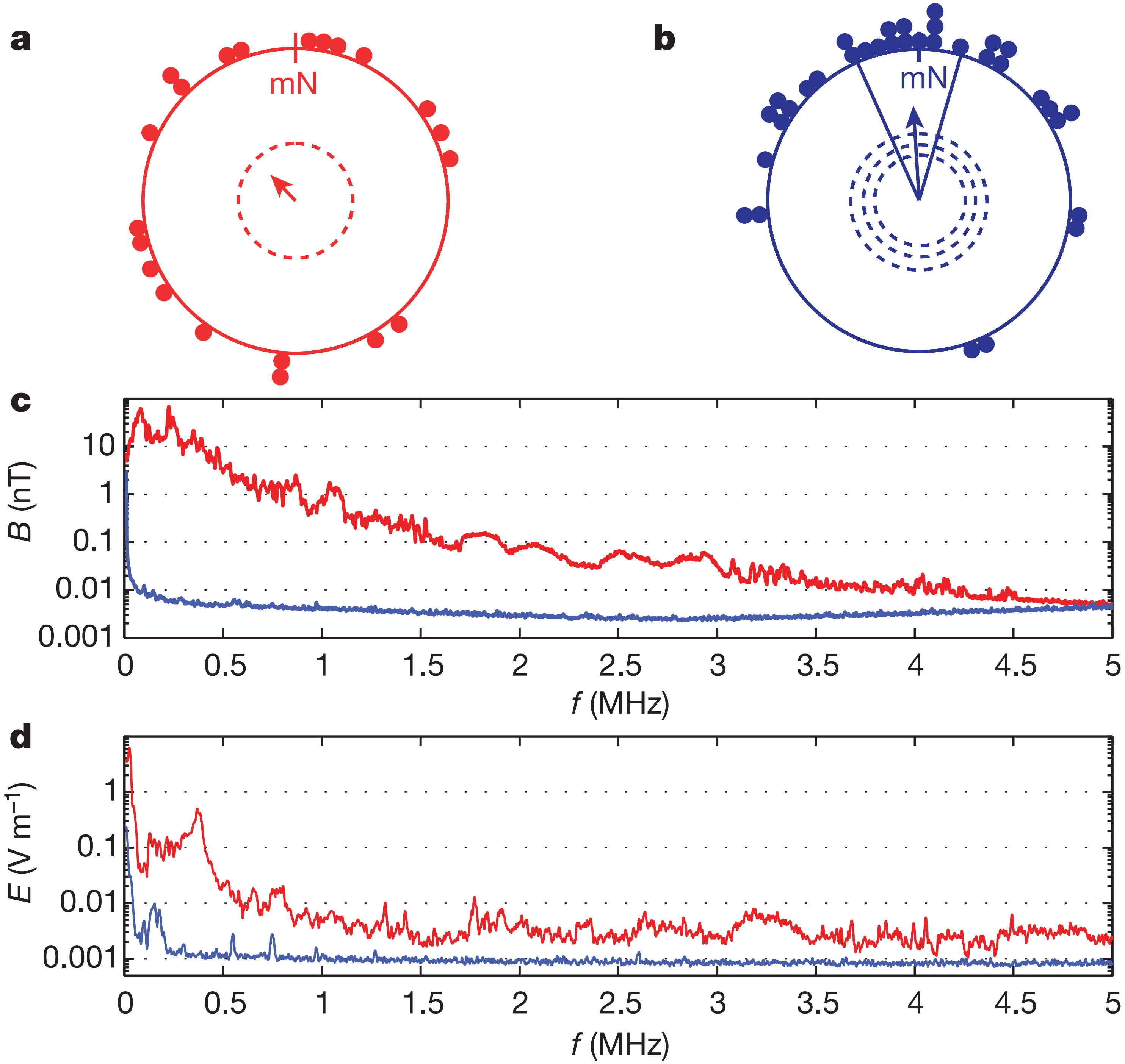


$$E_0 = c_0 B_0$$

$$c_0 = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$ *speed of light*

http://en.wikipedia.org/wiki/Electromagnetic_radiation

migratory European robins orient towards magnetic north



Earth's magnetic field
~ 49,000nT

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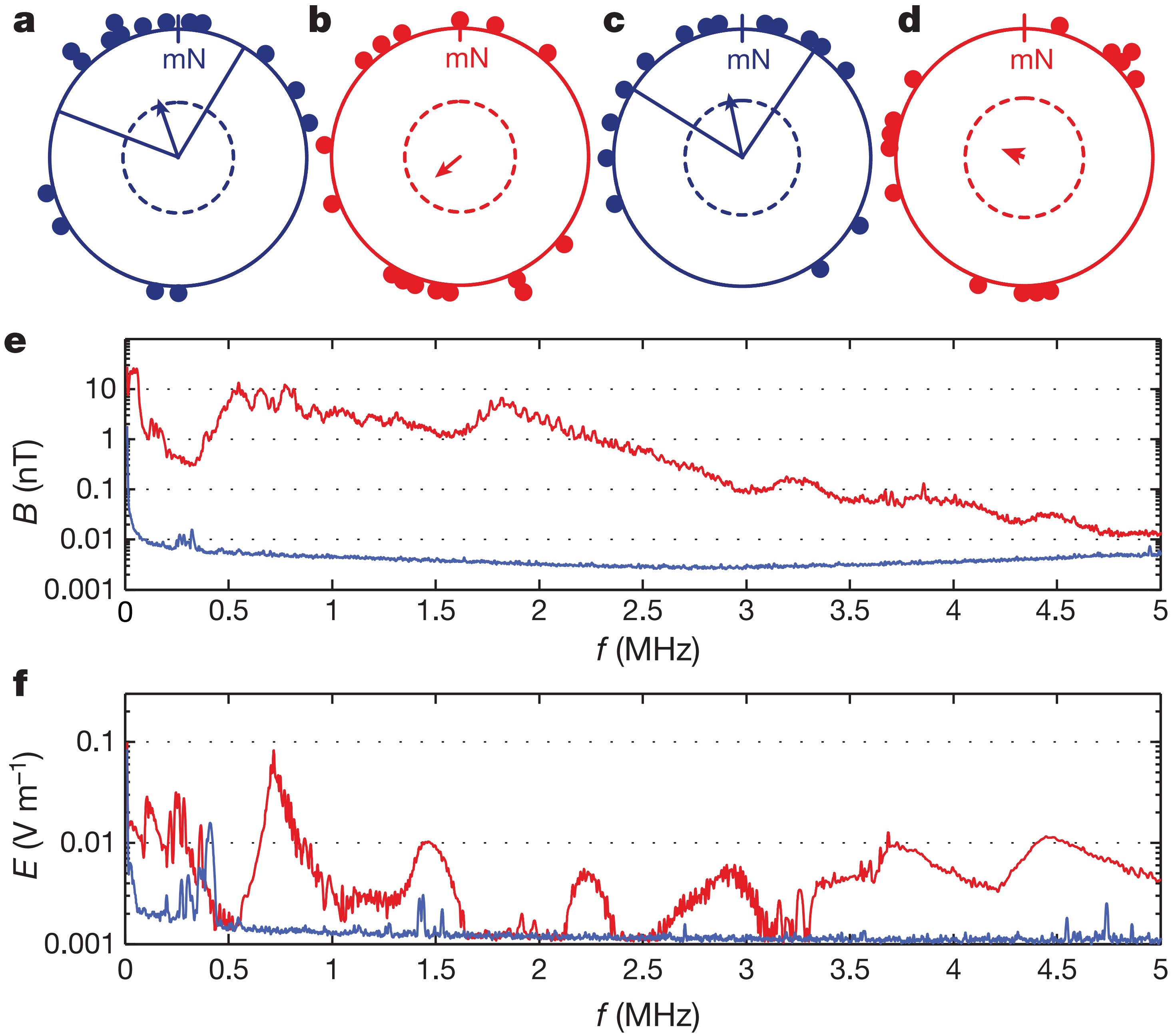

Figure 2 | Connecting and disconnecting the grounding of the screens turns on and off the birds' magnetic compass orientation capabilities. When the screens were grounded, European robins oriented significantly in their migratory direction (**a**, spring 2008, $n = 16$, mean direction $341^\circ \pm 40^\circ$, $r = 0.45$, $P = 0.04$), whereas they were randomly oriented when the grounding was disconnected (**b**, spring 2008, $n = 16$, mean direction 230°, $r = 0.22$, $P = 0.47$). In another set of identical tests, this pattern repeated itself (**c**, grounded screens, spring 2008, $n = 15$, mean direction $348^\circ \pm 41^\circ$, $r = 0.48$, $P = 0.03$; **d**, grounding disconnected, spring 2008, $n = 14$, mean direction 290°, $r = 0.12$, $P = 0.82$). **e**, **f**, Magnetic and electric field intensities, respectively, as a function of frequency when the screens were grounded (blue) or ungrounded (red).

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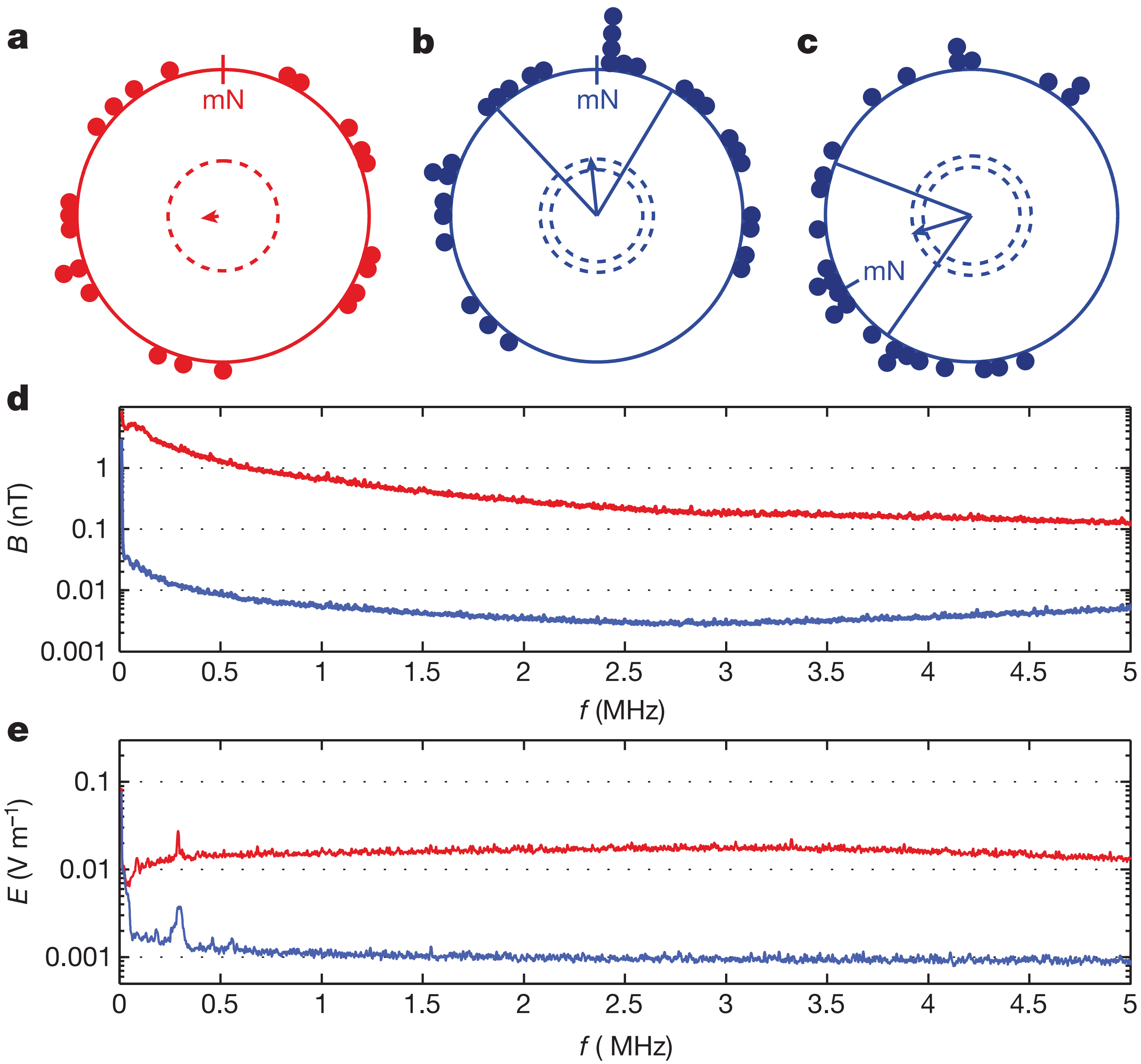

Figure 3 | Artificially produced broadband electromagnetic noise disrupts the magnetic compass orientation of birds tested inside the grounded aluminium-screened huts. Broadband, noise-modulated, electromagnetic fields between 2 kHz and 5 MHz (red traces in **d**, **e** and Extended Data Fig. 2) added inside the grounded screens resulted in disorientation of the birds (**a**, autumn 2010, $n = 22$, mean direction 278°, $r = 0.07$, $P = 0.91$). When the same equipment sent out the weakest possible broadband electromagnetic noise (blue traces in **d**, **e** and Extended Data Fig. 2), the birds oriented significantly towards North (**b**, spring 2011, $n = 30$, mean direction 354° ± 38°, $r = 0.39$, $P = 0.009$) and turned their orientation appropriately when the static magnetic field was rotated −120° (**c**, spring 2011, mN at 240°, $n = 27$, mean direction 253° ± 38°, $r = 0.41$, $P = 0.008$). **d**, Magnetic field intensity. **e**, Electric field intensity.

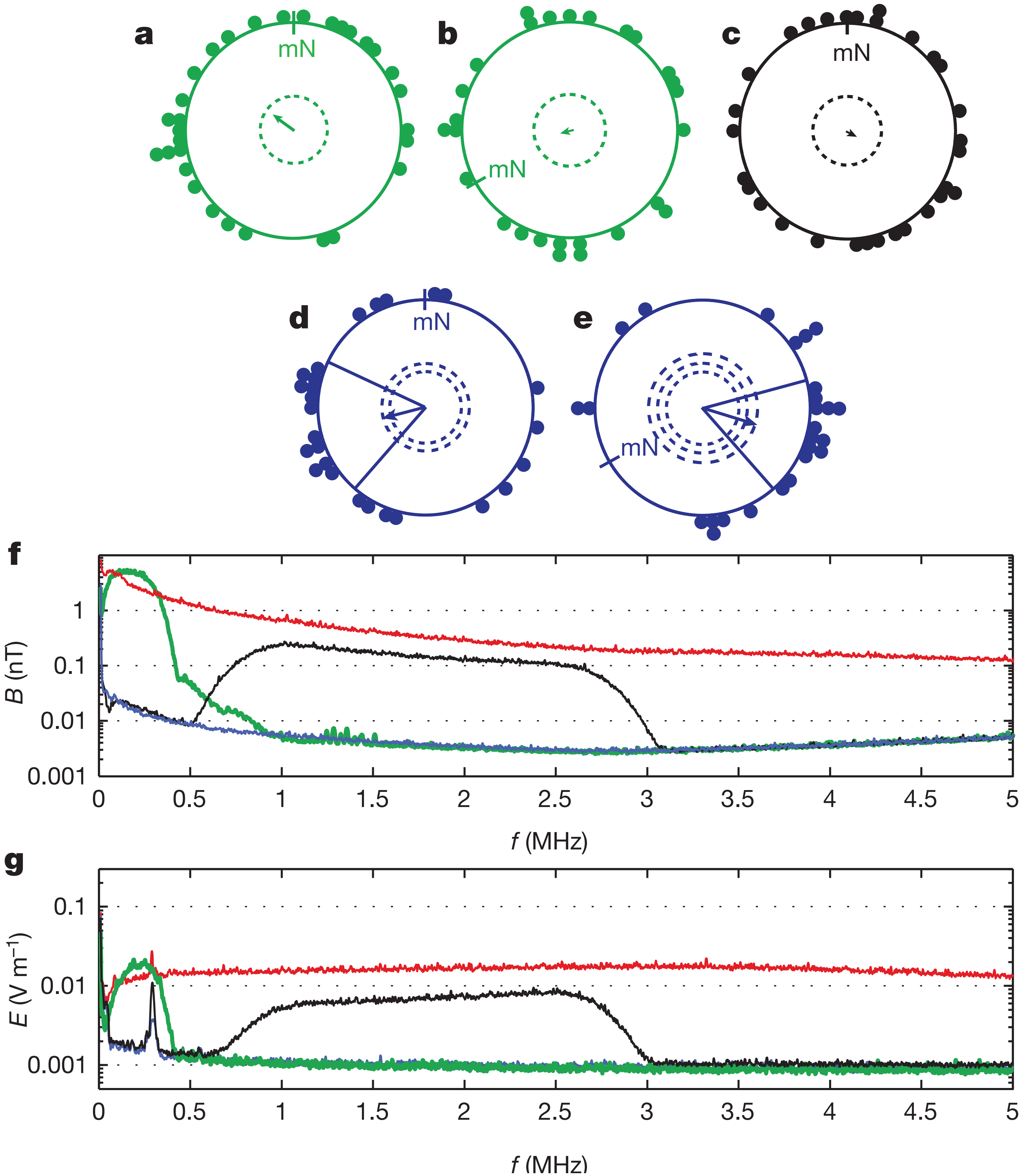

Figure 4 | The disruptive effect of broadband electromagnetic noise on magnetic compass orientation is not limited to a single narrow frequency range. Addition of broadband, noise-modulated, electromagnetic fields between ca. 20 kHz and 450 kHz (green traces in **f**, **g**) inside the grounded screens resulted in disorientation of the birds in the normal field (**a**, autumn 2011, $n = 31$, mean direction 306°, $r = 0.24$, $P = 0.17$) and in a field turned $-120°$ horizontally (**b**, autumn 2011, $n = 27$, mean direction 235°, $r = 0.03$, $P = 0.96$). Broadband fields between ca. 600 kHz and 3 MHz (black traces in **f**, **g**) also disoriented the birds (**c**, autumn 2011, $n = 30$, mean direction 108°, $r = 0.11$, $P = 0.70$). When the same equipment sent out the weakest possible broadband electromagnetic noise (blue traces in **f**, **g**), the birds showed appropriately directed magnetic compass orientation (**d**, autumn 2011, $n = 27$, mean direction $258° \pm 37°$, $r = 0.42$, $P = 0.008$), and responded to a $-120°$ horizontal rotation of the static field (**e**, autumn 2011, $n = 26$, mean direction $107° \pm 32°$, $r = 0.51$, $P < 0.001$). For comparison, the red traces in **f**, **g** show the intensity of the strong 2 kHz–9 MHz broadband noise used for the experiments presented in Fig. 3. **f**, Magnetic field intensity. **g**, Electric field intensity.

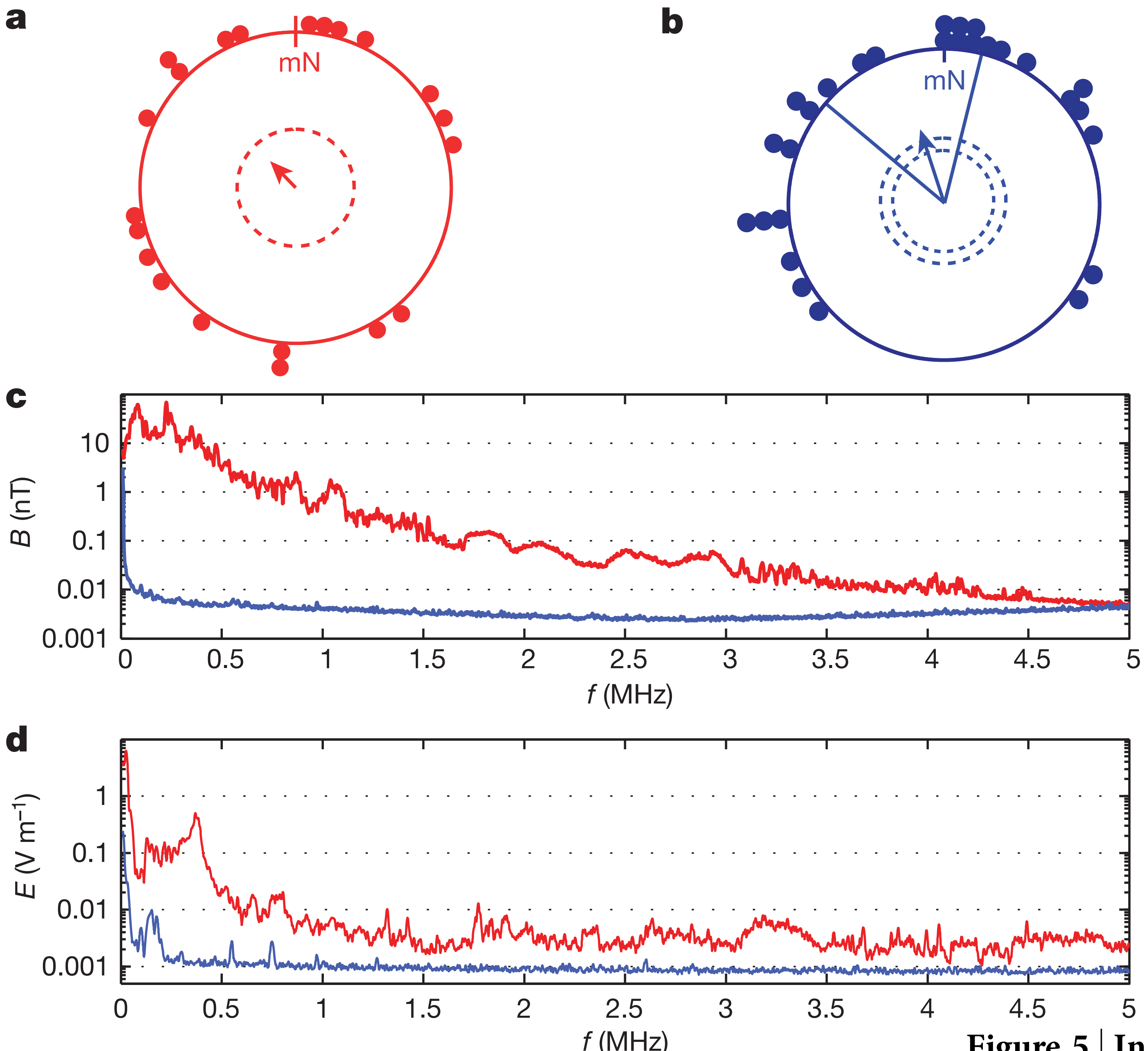

Figure 5 | In a rural location, European robins show magnetic compass orientation without screening. **a**, Orientation at the University campus (same data as in Fig. 1a). **b**, Orientation at a rural location (spring 2011, $n = 28$, mean direction $342^{\circ} \pm 32^{\circ}$, $r = 0.47$, $P = 0.002$) where the anthropogenic electromagnetic noise was much weaker (blue traces in **c**, **d**) than at the University (red traces in **c**, **d**). **c**, Magnetic field intensity. **d**, Electric field intensity.

final thoughts

- disruption of magnetic compassing is localized to "urban" areas (AM radio, electronic equipment...)
- but night-migratory song-bird populations are dwindling rapidly
- how are birds so sensitive? what is the mechanism? perhaps birds also sense electric fields?