

## BRIEF COMMUNICATIONS

## Nectar bat stows huge tongue in its rib cage

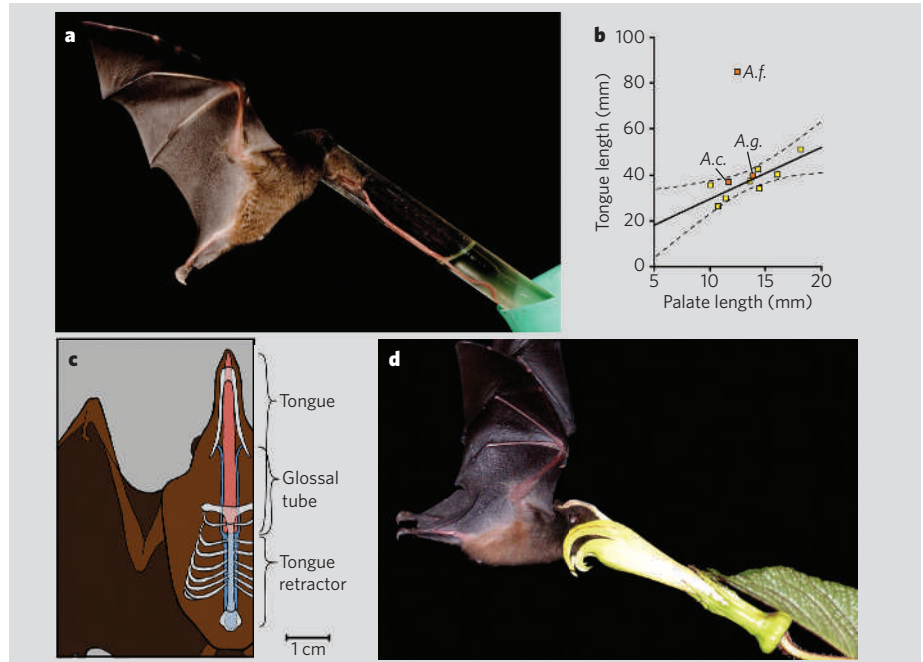
The extreme length of this bat's tongue might have coevolved with the long flowers it pollinates.

Bats of the subfamily Glossophaginae (family Phyllostomidae) are arguably the most specialized of mammalian nectarivores, and hundreds of neotropical plants rely on them for pollination<sup>1,2</sup>. But flowers pollinated by bats are not known to specialize for bat subgroups (unlike flowers that have adapted to the length and curvature of hummingbird bills, for example), possibly because the mouthparts of bats do not vary much compared with the bills of birds or the probosces of insects<sup>3,4</sup>. Here I report a spectacular exception: a recently-described nectar bat that can extend its tongue twice as far as those of related bats and is the sole pollinator of a plant with corolla tubes of matching length.

The nectar bat *Anoura fistulata* was discovered in the cloud forests of the Andes of Ecuador, where it lives with two other glossophagines, *A. caudifer* and *A. geoffroyi*<sup>5</sup>. I measured the tongues of these bats by placing them in separate flight cages and training them to drink sugared water from a modified straw (6 mm in diameter; see supplementary information). The *A. caudifer* drank to a maximum depth of 36.7 mm ( $\pm 2.28$  s.d.,  $n = 6$ ) and the *A. geoffroyi* to 39.3 mm ( $\pm 2.21$  s.d.,  $n = 5$ ). The tongue of the *A. fistulata*, however, reached 84.9 mm ( $\pm 3.51$  s.d.,  $n = 4$ ), which is 150% of its body length (Fig. 1a). This relative tongue protrusion is greater than that seen in any other mammal, and is second only to the chameleon<sup>6</sup> among the vertebrates.

Across the glossophagine nectar bats, maximum tongue extension is tightly correlated with the length of their rostral components, such as the palate and mandible<sup>7</sup>. Although the correlation holds for *A. caudifer* and *A. geoffroyi*, *A. fistulata* falls far outside the 95% confidence interval (Fig. 1b). Close examination of tongue morphology reveals the basis for this pattern. In other nectar bats, the base of the tongue coincides with the base of the oral cavity<sup>8</sup> (the typical condition for mammals), but in *A. fistulata* the tongue passes back through the neck and into the thoracic cavity. This portion is surrounded by a sleeve of tissue, or glossal tube, which follows the ventral surface of the trachea back and positions the base of the tongue between the heart and the sternum (Fig. 1c).

Darwin famously (and correctly) predicted that the long-spurred Malagasy star orchid (*Angraecum sesquipedale*) would be pollinated by a hawkmoth with an extremely long proboscis<sup>9</sup>. Likewise, a nectar bat that has such extreme tongue extension points to the existence of a flower that has a corolla of comparable length.



**Figure 1 | Protrusible tongue of the nectar bat *Anoura fistulata*.** a, *Anoura fistulata* feeding from a test tube filled with sugared water; its tongue (pink) can extend to 150% of body length. b, Relation between maximum tongue extension and palate length for 11 species of glossophagine nectar bat. *Anoura fistulata* (*A. f.*) is an outlier; solid line, regression for ten other bats ( $y = 2.25x + 6.78$ ,  $r^2 = 0.68$ ); dashed lines, 95% confidence intervals. Orange squares, *A. fistulata*, *A. geoffroyi* and *A. caudifer*; yellow squares, data for species from ref. 7 (from left, *Lichonycteris obscura*, *Glossophaga comissarisii*, *G. soricina*, *Hylonycteris underwoodi*, *A. cultrata*, *Lonchophylla robusta*, *Leptonycteris curosoae*, *Choeronycteris mexicana*). c, Ventral view of *A. fistulata*, showing tongue (pink), glossal tube and tongue retractor muscle (blue), and skeletal elements (white). d, *Anoura fistulata* pollinating the specialized flower of *Centropogon nigricans*; because of the long corolla, only *A. fistulata* can reach its nectar. (Fig. 1a, M. Cooper; Fig. 1d, N. M.)

Dietary studies of *Anoura* in four reserves on the eastern and western slopes of the Andes confirm this prediction. During 129 nights of mist-netting in 2003–05, I captured 46 *A. geoffroyi*, 38 *A. caudifer*, and 21 *A. fistulata*, and identified the pollen on their fur and in their faeces. Pollen from *Centropogon nigricans*, which has corollas 8–9 cm long, was carried only by *A. fistulata* (Fig. 1d), as might be expected, given that other *Anoura* could not reach this flower's nectar. During 55 hours of nocturnal and diurnal videotaping of 12 flowers of *C. nigricans*, ten bats were the only visitors. This observation, combined with the finding that *A. fistulata* was the only bat visitor, supports the conclusion that *A. fistulata* is the only pollinator of this plant.

Specialization on one species of pollinator is exceedingly rare in angiosperms<sup>10</sup>, and *C. nigricans* is the only example known in flowers pollinated by bats. After the initial evolution of

a glossal tube, the extreme tongue length of *A. fistulata* probably coevolved with long flowers such as those of *C. nigricans*. In an example of convergent evolution, pangolins (scaly anteaters) also have a glossal tube<sup>11</sup>; despite their different diets, ant-eating and nectar-feeding animals face similar evolutionary pressures for highly protrusible tongues, and pangolins and *A. fistulata* have independently converged on a similar solution.

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## NAVIGATION

# Bat orientation using Earth's magnetic field

Bats famously orientate at night by echolocation<sup>1</sup>, but this works over only a short range, and little is known about how they navigate over longer distances<sup>2</sup>. Here we show that the homing behaviour of *Eptesicus fuscus*, known as the big brown bat, can be altered by artificially shifting the Earth's magnetic field, indicating that these bats rely on a magnetic compass to return to their home roost. This finding adds to the impressive array of sensory abilities possessed by this animal for navigation in the dark.

For some taxa, navigation behaviour can be readily investigated in the laboratory<sup>3</sup>. To study the wide-ranging navigation of bats, however, their flight path needs to be tracked in a natural setting. Limitations of the available technology make this a labour-intensive process, so bat navigation is relatively poorly understood compared with that of other animals<sup>2</sup>.

We used radio telemetry from a small aircraft<sup>4</sup> to track big brown bats displaced 20 km north of their home roost (for methods, see supplementary information). A control group released from this site headed in a direction significantly towards home (see supplementary information) at 5 km from the release site (Fig. 1a).

To test whether bats use the Earth's magnetic field, we exposed two groups of bats to a rotated magnetic field, one 90° clockwise and one 90° anticlockwise with respect to magnetic north, for a period from 45 min before to 45 min after

sunset. This also allowed us to test whether the Earth's magnetic field was being used in conjunction with other cues, such as the sunset or stars<sup>5</sup> (see supplementary information).

The headings of the clockwise group were significantly oriented in an easterly direction (90°) at 5 km from the release site, whereas the anticlockwise group moved significantly in a westerly (270°) direction; the two groups showed a significant difference (Fig. 1a). These different initial orientations of the groups indicate that they may have been using a sunset-calibrated magnetic compass<sup>5,6</sup>.

Some experimental bats corrected and homed during the same night, despite being initially orientated away from home (Fig. 1b, c). Although such behaviour has previously been unknown in bats, homing pigeons can correct and return home after an initial deviation when clock-shifted<sup>7</sup>. We suggest that the deflected bats that nevertheless home during the same night recognize a mismatch between the direction they are flying and their navigational map.

Besides the application described here to measure bat navigation, radio telemetry has also been used to investigate migration in insects<sup>8</sup>. The possibility of transmitting such radio signals to low orbiting satellites should open up field studies on the orientation, navigation and migration of small, wide-ranging animals.

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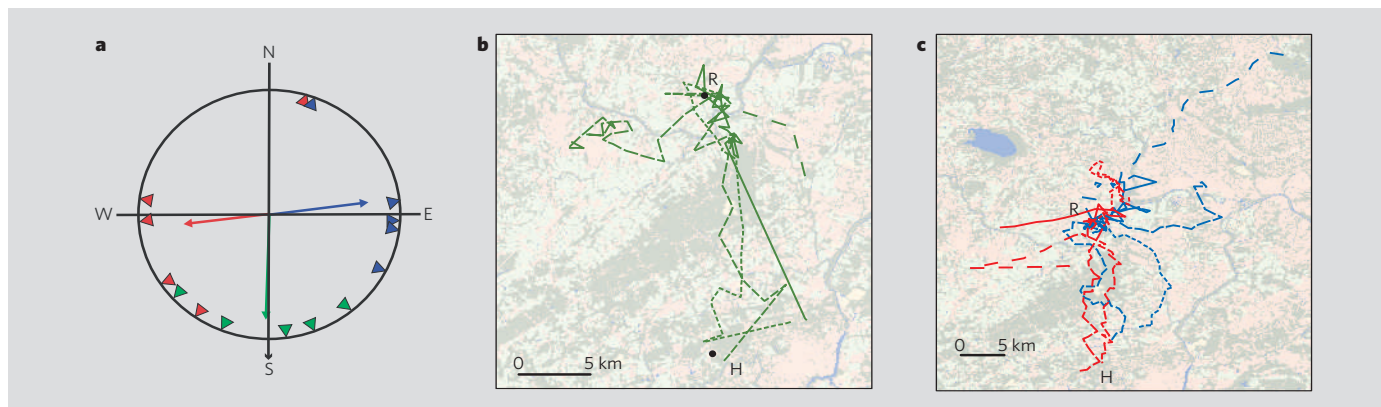
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**Figure 1 | Headings and tracks of homing bats.** **a**, Heading directions at 5 km after release 20 km north of the home roost (to south; black arrow). Arrowheads, directions for individual bats; arrows, mean direction for the group. Red, anticlockwise (ACW) rotation of magnetic field by 90° with respect to north; blue, clockwise (CW) rotation of magnetic field by 90°; green, controls (no rotation of magnetic field). Orientation was significantly southerly in controls (V test, 180°,  $U = 2.862$ ,  $P = 0.0072$ ); westerly in ACW bats (V test, 270°,  $U = 1.973$ ,  $P = 0.023$ ); and easterly in CW bats (V test, 90°,  $U = 2.66$ ,  $P = 0.002$ ). Headings differed significantly between the three groups (Watson–Williams 3-sample test:  $F = 16.808$ ,  $P = 0.00033$ ; pairwise: CW vs control,  $F = 23.774$ ,  $P = 0.001$ ; ACW vs control,  $F = 6.733$ ,  $P = 0.032$ ; ACW vs CW,  $F = 23.503$ ,  $P = 0.001$ ). **b**, **c**, Control (**b**) and experimental tracks (**c**) of bats, with different dotted and dashed lines for individual bats ( $n = 5$  in each group). Colours indicate direction of rotation of magnetic field, as in **a**. R, release site; H, home.