BIRD'S EYE VIEW of NAVIGATION

A stork found in Germany in 1822 with a central-African hunting spear through its neck was the earliest proof that birds migrated in winter, rather than hibernating or changing form.

Every autumn, billions of birds disappear from our fields, trees, and shorelines to make awe-inspiring migratory journeys, reliably returning again the next spring.

The bar-tailed godwit, a long-legged wading bird, flies from Alaska to New Zealand over nine straight days without stopping. Short-tailed shearwaters migrate all the way round the Pacific with pinpoint accuracy, returning to the same burrow year-on-year. Astonishingly, we still don't understand how any of these birds know where they're going.

Centuries ago, there wasn't even a clear explanation for the bewildering seasonal disappearance of many bird species. Charles Morton, a 17th century English minister, was sure that birds flew to the moon and back each winter. Other popular theories included birds hibernating at the bottom of the sea, or even that they turned into mice on an annual basis.

One of the earliest pieces of evidence that pointed towards an annual migration was the so-called *Pfeilstorch* ("arrow-stork" in German). In 1822, near the German village of Klütz, a white stork appeared with an entire African hunting arrow embedded in its slender neck. It had been injured while wintering in Africa, and somehow managed to make its way back to its breeding grounds.

Evidence like this helped us understand that each year many birds in fact migrate from their summer homes when the weather starts to turn chilly, searching for warmer climes with better shelter and richer food supplies. What is not so well-undestood is how these birds navigate on their long journeys.

What we do know is that some birds, and many other migratory animals, possess a sense that detects the Earth's magnetic field. This provides information that they use for both orientation and navigation – a kind of built-in satnav. There are two competing theories behind how this compass-map sense works: the first involves small magnetic particles in the bird's body aligning with the Earth's magnetic field, like a traditional compass, whereas the second relies on a light-dependent chemical reaction in the bird's eye for compass information.

This second theory, which is the leading hypothesis, suggests that the distribution of the products of the chemical reaction depends on the orientation of the bird's head with respect to the Earth's magnetic field. Imagine the magnetic field as something like a tap or valve, controlling the flow to two separate pipes: the direction of the tap controls how much of each product pours out, which the bird then interprets as directional information.

It seems doubtful that the Earth's weak magnetic field could affect a chemical reaction, since the energy associated with the Earth's field is around nine million times weaker than thermal energy at room temperature. However, the chemicals involved are in an excited state far from equilibrium, meaning that even small effects can influence the outcome of the reaction.

These special excited states occur when light of a particular wavelength enters the birds' eyes. We know that light is important for navigation because migrating birds such as European robins can orient themselves in their migratory direction under blue or green light, but not red or yellow. The fact that this light-dependent reaction seems to occur in birds' eyes suggests that they might actually see the Earth's magnetic field, like some kind of avian heads-up display.

As well as compass information, we know that birds also learn a kind of magnetic map during their lifetime. Virtual displacement experiments can even trick birds into thinking they are somewhere else by artificially supplying them with the magnetic field for a different location. Reed warblers in Russia will usually migrate south-west towards sub-Saharan Africa come winter, but in one experiment they were kept in a magnetic field of the same strength and direction as found in Scotland. The adult birds consequently changed their migration behaviour completely, setting off south-east, the appropriate direction to get to their destination from Scotland. When the experiment was performed on juveniles they were instead completely disoriented, showing that the birds must learn this magnetic map on their first migration.

There are still many unanswered questions in this field: which specific molecules sense the magnetic field? How is this information processed? How do birds handle confusing magnetic information due to, for instance, electromagnetic noise over large cities? How do birds know when to start migrating, or when to stop? And how do they know where to go on their first migration? But it's safe to say we've made plenty of progress since we believed that birds simply swam down to the seabed and slept all winter.