Many animals use the Earth’s magnetic field for orientation. But exactly how they do this remains for the most part a mystery. In the Oldenburg-based Collaborative Research Centre “Magnetoreception and Navigation in Vertebrates”, researchers from various disciplines are working together to solve the puzzle.

A unique spectacle awaits anyone who visits the German island of Heligoland in the spring or autumn: on some days, particularly after bad weather, thousands of migratory birds including small songbirds such as robins, northern wheatears, chiffchaffs and song thrushes stop to rest on this rocky archipelago in the middle of the North Sea. Some spend the summer in Scandinavia or Russia. A few northern wheatears even fly across the Atlantic to Canada in the warmer months to breed and raise their young. In winter, the birds migrate to warmer climes in southern Europe or Africa. Professor Henrik Mouritsen, who heads the Neurosensory Science research group at the University of Oldenburg, points to a particularly surprising aspect of this phenomenon: “Most songbirds migrate at night. Young birds that have never flown this route before migrate alone, without their parents or siblings,” he explains. Northern wheatears - pretty little songbirds that weigh just 25 grams - cover distances of up to 15,000 kilometres a year. “Their navigation systems are incredibly precise. Experienced migratory birds can find their way back to the exact same burrow they used for breeding the year before after flying up to 15,000 kilometres,” says the biologist. The big question for Mouritsen is how exactly they do this - with a brain that in most cases weighs less than a gram.

Mouritsen has been searching for answers for a long time and his research has made significant contributions to solving the mystery. Since 2019 efforts have intensified. The biologist is working with a large international team in the Collaborative Research Centre (CRC) “Magnetoreception and Navigation in Vertebrates: from biophysics to brain and behaviour”, which is conducting in-depth research into the impressive orientation abilities of vertebrates. The focus is on migratory birds such as European robins and blackcaps, and their astonishing ability to use the Earth’s magnetic field for orientation. Researchers from a wide range of disciplines including neurobiology, quantum physics, biochemistry, computer modelling and behavioural biology have joined forces in the CRC to find out how this still poorly understood sensitivity to the planet’s magnetic field works. Led by Mouritsen, the team is studying the pheno-
Görtemaker studies its interactions with other proteins.

in the tube) is only stable for a short time. PhD student Katharina

The light-sensitive protein cryptochrome 4 (the yellow substance

be sensitive to the field lines of the

such as European robins, appears to

found in the retinas of migratory birds

sensor has already yielded a hot con-

ence biomolecules. However, together

Mouritsen admits that at first glance it is hard to

internal clock. Each animal species has

position and motion of all the

atoms in a protein using the funda-

menon at all levels: analysing migra-

tion routes, conducting behavioural

In Mouritsen’s group.

Biology and Computational Physics

Ilia Solov’yov, head of the Quantum

Oxford were then able to demonstrate

large quantities of cryptochrome 4 in

a doctoral student in Mouritsen’s re-

search group, succeeded in producing

large quantities of cryptochrome 4 in

in tiny increments of time. For just one

microsecond – a millionth of a second –

he needs two weeks of computing time

on a powerful supercomputer.

But it’s worth the effort: with his

“computer microscope”, Solov’yov can

uncover things that remain hidden

using other methods – such as how

electrons jump from amino acid to

amino acid within the cryptochrome,

measuring electron spin in these two

radicals.

While the secrets of this unique protein

are gradually being revealed, bioche-
mist Karl-Wilhelm Koch is investiga-
ting how the stimulus it provides is

transmitted further inside the cells.

“The perception of the magnetic field

has to be translated into the language of

the nervous system,” he explains.

With the help of his "computer microsco-

pe", Solov’yov has already been able to

extract information about the in-

teractions of cryptochromes with other

proteins.

Another technique used to find interaction partners is the

Fano-Hybrid System involving petri dishes filled with a nutrient

medium.

Numerous tests in the lab are needed to gain insights into the com-

plex biochemical interactions that make magnetic field perception

possible.

A successful search in gene libraries

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Doctoral student Vaishnavi Balaji uses a high-resolution confocal microscope to study how neurons inside the retina are interconnected.

subproject tasked with deciphering the nerve connections within the retina. These unusually shaped nerve cells consist of a larger principal member and smaller accessory member and make up about 30 to 40 percent of the photoreceptor cells in avian eyes. The CRC team thinks it likely that the cryptochrome molecules are not floating around freely in these cells but are in some way tethered. In the peripheral areas of the photoreceptors there are hundreds of parallel cell membranes. The scientists suspect that the proteins are fixed and aligned in such a way to increase their sensitivity to the direction of the magnetic field.

Dedek believes the peculiar geometry of the double cones makes them particularly suited to detecting the magnetic field: “For example, if the cryptochrome molecules in the two subunits are perpendicularly to each other, that could aid the process of distinguishing between visual and magnetic stimuli.” To understand how the retina encodes the stimuli, Dedek and his team set up various radio receiving stations on the island and around the German Bight to track the departure direction of robins and northern wheatears when leaving Helgoland. The researchers then attached radio transmitters weighing 0.3 gram to some 140 northern wheatears and 140 robins and exposed the birds to low levels of electromagntic field or no electromagntic field at all for several hours. “We then released them and used the radio telemetry data to see how they behaved,” he says. “We observed that more fascinating findings are yet to come: “We have achieved the easy part of our research objectives. Now things will get even more exciting!”

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Investigating magnetoreception

The Collaborative Research Centre (CRC) “Magnetoreception and Navigation in Vertebrates: from biophysics to brain and behaviour” led by Henrik Mouritsen (photo) has two central objectives: to understand how vertebrates detect the Earth’s magnetic field and to investigate what other information birds, fish and bats use for navigation. In five subprojects the focus is on how magnetic signals are detected at the molecular level. Six other projects within the CRC are investigating neural processing of magnetic information and its integration with other relevant cues in the retina and in the brain. One goal here is to find out how the brain links different kinds of sensory information and which areas of the brain represent maps and compass information. In four other subprojects, the main focus is navigational behaviour. The researchers are testing their hypotheses in the lab and in wild/free-flying birds and bats and in free-swimming fish. Last but not least, there is a project investigating the genetic basis of migratory behaviour, for example the inherited propensity to migrate that compels many birds to cover vast distances every year. The knowledge gathered in the CRC is important for protecting endangered migratory birds and could also be used to design better sensors or develop quantum computers. In addition to the University of Oldenburg, the Institute of Vertebrate Research in Wilhelmshaven, the Universities of Bochum and Cologne, Oxford University (UK) and the Weizmann Institute of Science in Israel are also participating in the CRC.