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# *WHAT DOES A BEE SEE? USING TOMOGRAPHY TO UNDERSTAND THE VISUAL WORLD OF INSECTS*

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**Keywords:** x-ray tomography, eye, insect, flight control, navigation

**Summary:** We use x-ray tomography to develop 3D models of the eyes of bees. This enables us to reconstruct what they see which, combined with data from behavioural experiments, allows us to understand how their miniature brains use visual information to perform complex behaviours such as long distance navigation.

## 1. OVERVIEW

Understanding how brains generate complex behaviour is one of the fundamental challenges facing neuroscience. How, for example, are we able to navigate over long distances and to find our way back again? What information does the brain use to do know where it is and to guide the body into the correct direction? While it is currently impossible to answer these questions for humans, a great deal can be learned from studying the complex behaviour of animals with smaller brains, such as insects. This is because all behaviour can be broken down into principal elements, such as a decision to turn left or right, to speed up or slow down and it is likely that similar processes underlie these decisions in most animals, from bees to humans. Each of these elements are guided by information from the outside world that is transmitted to the brain through sensory organs.

Insects such as bees are capable of navigating over large distances through complex environments, maintaining flight and avoiding collisions with obstacles as they do so. How do their miniature brains (comprising 0.000001% of the neurons of a human brain) and sensory systems coordinate the behavioural tasks required for achieving such remarkable feats? The overall aim of my research is to answer this question using a variety of approaches that range from behavioural experiments to x-ray tomography.

Behavioural research in my lab [1,2] has shown that bees rely heavily on vision to control their flight and to navigate. This is because vision provides the most reliable information about how the animal is moving through the world and in which direction it is heading. Much of the work in this area has focussed on developing mathematical models to explain how the brains of bees use vision to guide their flight. Although we have made great progress in understanding the mechanisms underlying navigation behaviour in bees, our efforts are currently limited because we do not know exactly what visual information the brains receive, that is, we still do not understand exactly what a bee sees. This is where x-ray tomography plays an important role. By generating high resolution 3D anatomical models of bee eyes, we can begin to understand exactly how visual information is transmitted through the visual system to the brain. By combining this with analyses of the visual habitat in which bees have evolved, we can also use this to simulate exactly how they experience their visual world. This not only helps us to understand how the brain uses sensory information to control behaviour, it can also give important insights into the visual adaptations necessary for performing visually guided behaviour in different habitats.

Bees can be found in an extraordinarily diverse range of environments, from the open landscapes in the Arctic circle to the dense tropical rainforests of Central America. These environments produce vastly different visual cues and present different challenges to bees or any other animals that use vision to navigate through them. The visual system of insects is excellent for investigating sensory adaptations because it is highly plastic and is therefore likely to have developed optimal adaptations for controlling behaviour in these different visual habitats. Indeed, our preliminary analyses using standard microscopy techniques indicated that the eyes of tropical bees are different from those of more temperate species. For example, the relative size and shape of the large compound eyes, as well as their position on the head differs from temperate species, suggesting that these bees have not only different fields of view but also differences in their spatial resolution and sensitivity. Another clear difference between the visual systems of these bees is the position and arrangement of the three ‘simple eyes’ or ‘ocelli’ that lie at the top of the head. In the temperate species, these ocelli face frontally and are arranged in a straight line. In the tropical species, however, these eyes are in a more triangular arrangement and are facing upwards [3]. These differences have dramatic consequences for both the visual fields of these eyes and the sort of visual information that they would receive. To be able to understand what the eyes of bees from different habitats see, and therefore understand how they use visual information for guidance and navigation, we created high-resolution 3D reconstructions of their heads and eyes from micro CT scans performed at a lab tomograph at the Department of Solid Mechanics at Lund University and at the I13 beamline at the Diamond Light Source. From these 3D models, we have performed various analyses that have allowed us to calculate the visual fields as well as the sensitivity and resolution across the eyes of different bee species in order to better understand how their eyes are adapted to navigation in their visual habitat. Combined with data from behavioural experiments, we will use this data to simulate the visual world of insects and to generate models of how brains can use visual information to guide complex behaviour.

## References

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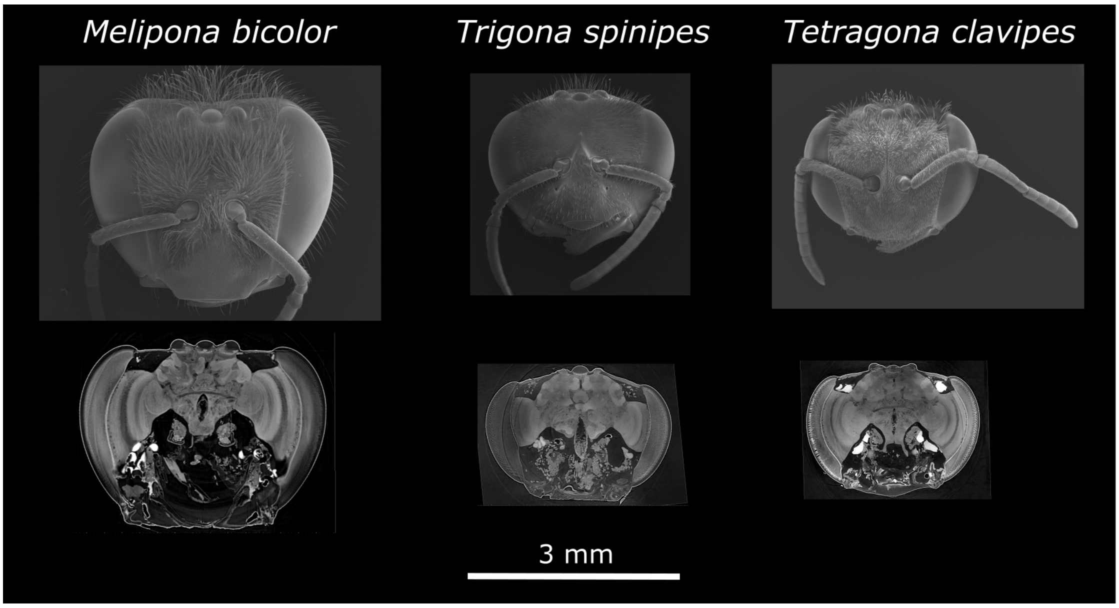


**Figure 1:** How x-ray tomography can help us to understand the visual world of bees. Top row: SEM scans of the heads and eyes of different bee species that are being used to understand how the visual system is adapted to different visual habitats. Bottom row: x-ray tomographic scans of the same bee species showing the internal architecture of the eyes and brains. Analyses of the 3D structure of the eyes can be used to determine what visual information reaches the brain.