People & Ideas

Markus Grebe: Bringing plant polarity to light

Grebe studies the establishment and maintenance of cell and tissue polarity in plants

The apical/basal polarity of epidermal or epithelial cells is essential for the proper function of tissues. This is true whether the tissue in question is found in animals or plants. However, the strategies used to organize cell and tissue polarity in these different organisms are not universal.

Markus Grebe has been studying plants since the start of his research career. His work on the mechanisms by which polarity is established in plant cells (1–3) and tissues (4, 5) has highlighted both similarities (1) and differences (5) from analogous processes in animal cells. Wanting to hear more about his career and about the budding field of plant cell polarity, we called him at his laboratory at Sweden's Umeå University. We reached him just at the end of European Fascination of Plants Day, when the public is invited to learn more about plants and plant research.

PLANTING THE SEED

What first got you interested in a career in biology?

I grew up in a small town in a low mountain range in West Germany. There were forests and hills all around, and I would go there with just my dog for company. My parents and grandfathers would also take me on various hikes and outings to look at plants and animals. I think this was probably what originally made me feel close to nature and the natural sciences.

By the age of 16, I was pretty sure that I wanted to do something with either forestry or biology. Ultimately, I decided I'd prefer to focus on inquiring about nature, rather than maintaining or managing it. That set me on the way to becoming a biologist.

When did you begin studying plant biology?

I went to university in the town of Giessen, where I had gone to high school, and there I received a very good education in classical biology: dissecting things and studying morphology. But there I also read a review paper by Paul Nurse on Cdc2 and the fission yeast cell cycle and became very interested in the molecular genetics of cell division.

I went to the University of Sussex in England as a visiting student to try to improve my English, and while I was there I joined the laboratory of Felicity Watts, who was working on DNA repair genes. She gave me a little project isolating DNA repair and cell cycle genes from *Arabidopsis thaliana*, a plant, by heterologous hybridization of genes from the fission yeast *Schizosaccharomyces pombe*. I liked the work so much that I continued to do my university diploma in Sussex.

I initially considered staying in England to do my PhD, but then I found a paper by Gerd Jürgens, a German geneticist, describing an interesting *Arabidopsis* mutant defective in a gene called *GNOM*. This mutant had very strong developmental defects in asymmetric cell division and in cell, tissue, and organ polarity. I thought this could be a really nice topic to work on, because it integrated asymmetric cell division into a developmental context in plants.

Auxin can be instructive in polarizing the cells within the plane of the tissue layer.

SPROUTING IDEAS

So you returned to Germany...

Gerd's group was at the University of Tübingen, but we were actually located in the Max Planck Institute for Developmental Biology, and it was an extremely exciting time to be there. The year I arrived, Christiane Nüsslein-Volhard, whose laboratory was in the same institute, received the Nobel Prize for her work on the development of the basic body plan of the *Drosophila* embryo.

PHOTO COURTESY OF KJELL OLOFSSON

Markus Grebe

By this time, around the mid-1990s, there was also a lot of work published using *Drosophila* wing hair polarization and ommatidia development as systems to analyze how cell polarity gets established within the plane of the tissue layer. My PhD project had more to do with protein–protein interactions than genetics, but I had become very interested in the question of how cell polarity is set up and how it is coordinated within tissues. I thought that what I should do for my postdoc was to use the *Arabidopsis* root, where you can easily combine genetics and cell biology, to address this question.

When did you first start working on planar polarity in plants?

Ben Scheres had developed the *Arabidopsis* root as a postembryonic system for studying pattern formation in plants. What I found particularly interesting for studies of cell and tissue polarity was that *Arabidopsis* root hairs share features with the wing hairs in flies. They are located very strictly at one end of the cell, and, if their position is shifted or if there's more than one hair per cell, one automatically knows there is something wrong. I thought this would be a great system to work with, so I joined Ben's laboratory in Utrecht, in the Netherlands. I really enjoyed working

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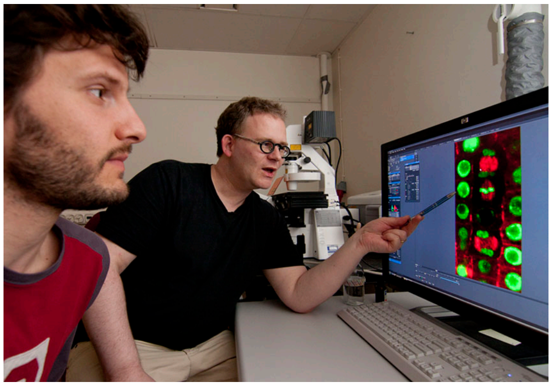

PHOTO COURTESY OF KJELL OLOFSSON

Grebe (right) and a PhD student discuss cell division in the *Arabidopsis* root.

with Ben because he gave me a free hand to do whatever I wanted and also let me take everything with me when I left.

How does the establishment of planar polarity in plants differ from the situation in animals?

In animals, one basically has the Frizzled pathway, which is needed for the coordination of planar polarity, and you have Wnt ligands that contribute to this. In plants, you don't have these genes. Instead, there is a hormone, auxin, which coordinates the polar positioning of root hairs in the epidermal cells. At the root tip, there is a very high concentration of this hormone, and there is also a strong concentration gradient of it in the tissue, decreasing as you get farther from the root tip.

Computational modeling studies also show that we can expect different auxin gradients in each of the individual epidermal cells—with the highest concentrations at the root tip end of the cell and lowest at the opposite end—but we cannot actually measure this directly.

FLOWERING CAREER

How is the auxin tissue gradient established?

Auxin is transported from cell to cell by specialized influx and efflux carriers. We have shown that it's possible to disrupt the gradient by making a triple mutant affecting two different auxin carriers and auxin biosynthesis. These mutant plants still have auxin in the whole root, but there is no differential accumulation on the tissue level anymore. That causes their root hairs to lose their orientation so that they sprout at either end of the cell.

When we then reintroduce auxin as a local source—for example, by putting beads soaked with auxin on these roots just behind the zone of cell division—then the hairs can always polarize toward this auxin source, either from the lower end of the root upward or from the upper end of the root downward. In this way, we showed that auxin can be instructive in polarizing the cells within the plane of the tissue layer.

How does this relate to individual cell polarity in the plant root epidermis?

The plant root is like a column with an epidermal layer like a sheet wrapping around its circumference. What we call the basal membrane of the root epidermal cell is the membrane oriented toward the root tip, and the apical membrane is on the opposite side of the cell oriented toward the shoot. The apical membrane is marked by one of the hormone carriers, PIN2, which helps in pumping auxin out of the cells away from the root tip, toward the shoot.

> Endocytosis, which is dependent on membrane sterols, is required to set up apical/basal polarity.

In somatic plant cells undergoing cytokinesis, you don't have a constriction of the cell as you would have in yeast or in animal cells. Instead you have vesicles fusing in the midplane of the cell to build the new cell plate. These vesicles contain PIN2, so, at first, both the new apical and the new basal membranes that form at the midplane have PIN2. But we showed in 2008 that mutants defective in sterol composition—which impairs endocytosis—fail to remove PIN2 from the new basal membrane. So endocytosis, which is dependent on membrane sterols, is required to set up apical/basal polarity within the cell.

This has become a focus in my group: looking at the function of membrane sterols and endocytosis in setting up cell polarity and also in the execution of cytokinesis in plants. We're also working on a planar polarity mutant defective in a protein that is conserved across eukaryotes but whose function isn't known in any organism. I'm quite excited about that, because it has defects in both the orientation of cell division and in planar polarity.

Do you still spend much time looking at plants outside the laboratory?

After I completed my postdoc I was recruited to a new research center in Umeå, Sweden, that my collaborator Göran Sandberg was setting up. Over the past 10 years, this place has become probably one of the best centers for plant science in Europe.

Before I visited the center, I never thought I would come here, because it's in the far north of Sweden. But actually it's a great place to enjoy the outdoors. My wife and I have a daughter who is two and a six-year-old son who I take cycling, fishing, and hiking. He loves to be outside, so maybe this summer or the next one we can try camping.

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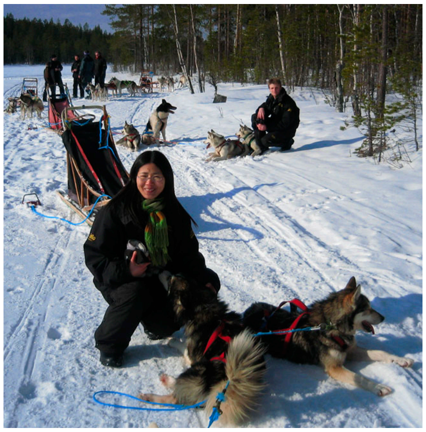

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The Grebe laboratory enjoys an outing on the frozen Vindeln River near Umeå.