Dominique Bergmann: Passionate about plant polarity

Bergmann studies stomatal development to discover how plant cells parse polarity and fate.

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Dominique Bergmann

Dominique Bergmann calls herself an outlier. Now a Gordon and Betty Moore Foundation Investigator of the HHMI at Stanford University, Bergmann first fell in love with cellular polarity and asymmetric cell divisions in graduate school. She was the only student in her lab studying the handedness of nematode body plans, which she could handily study by sight in the translucent worms.

As a postdoctoral fellow, she analyzed asymmetry in *Arabidopsis thaliana*—another organism with stunning visuals—at the Carnegie Institution for Science Department of Plant Biology in Chris Somerville's biofuelsfocused lab. She built her own lab on the premise that the beautifully simple development of the stoma, the plant two-cell breathing organ, was a powerful way to study how controlling cell divisions could lead to differing cell fates (1).

Her group discovered the three major transcription factors controlling stomatal development (2), including SPEECHLESS (SPCH), which controls entry into the stomatal cell lineage and is regulated by MAP kinases (3). Her group also found one of the first regulators of cell polarity in plants, BASL (4). Recently, her team identified which genes SPCH acts upon, providing the links between environmental and hormonal signals and the density of stomata breathing in carbon dioxide (CO_2) (5). Bergmann discussed with us her obsession with polarity and her work's relationship to climate change.

> "In plants... you have this whole record of developmental history."

SUCCESSFUL PLANTS

How did you land on investigating asymmetry in plants?

I'm very visual, and plants are absolutely gorgeous. And I guess it was a little bit of wanting to be out of the mainstream. I like the unexplored corners. Basic plant science gets about 1% of the funding of all biomedical sciences, so it's a pretty small group of scientists working on some very big problems. If you look at the surface of the Earth from a satellite, what you see are the plants. They are super successful—among the largest and the longest-lived organisms. They are continuously growing from incredible stem cell populations. I wanted to know how plants use asymmetric cell divisions to maintain their stem cell populations.

Do plants and animals ever solve these problems the same way?

The last common ancestor of plants and animals was just a single-celled organism, so, if it turns out that they use very similar molecules or pathways, there must be something fundamental about solving the problem in that way. This is exactly what we see with transcription factors like SPCH.

In cell polarity, plants, like animals, have to put a protein on one side of the cell and not the other side. Yet they don't encode any of the same molecules that we know from yeast or animals. So, in a way, you can start using plants as a test of theoretical cell polarity models. This is what we've been doing by identifying some of the players and rules in plants.

These polarity proteins are completely novel. Too novel, unfortunately. It's almost like, "It came from outer space—what on earth does it do?!" So it's been really informative to ask if these proteins behave in the way that's predicted by models of polarity that have been derived from animal data.

Why is stomatal development such a great model for studying asymmetric cell division (ACD)?

In plants, development does not involve cell migration or cell death, and, because cells are locked next to their neighbor and they have these distinct shapes, you can pretty much figure out who is related to whom. You have this whole record of developmental history, which is pretty remarkable.

Every leaf that forms is a new organ being generated from scratch. And it's going to pattern itself there as you watch it. You can watch stem cells being born.

And—they are like mammals in this way—it's not a rigid set of steps. It's got the flexibility to make more or fewer precursor cells to change and respond to the environment or internal conditions. On the flip side, we just published work showing that you can actually watch development run backward and dissect what happens when you reprogram a cell.

I'm in love with being able to watch all of this stuff.

POLAR EXPLORER

How did you identify BASL as a polarity factor in stomatal development?

BASL came out of a mutant screen looking for things that disrupted ACD. This one mutant had the dream phenotype—divisions weren't asymmetric anymore. But once we identified the gene, it really didn't look like anything else. To her credit, my former postdoc Juan Dong decided to figure out if this protein was interesting and made reporters for it.

I remember the day she showed me its localization. BASL appeared in the nucleus in some cells and as a polarized crescent in others. I jumped up and down and said, "Oh, my God! We've never seen that before!"

Text and Interview by Kendall Powell
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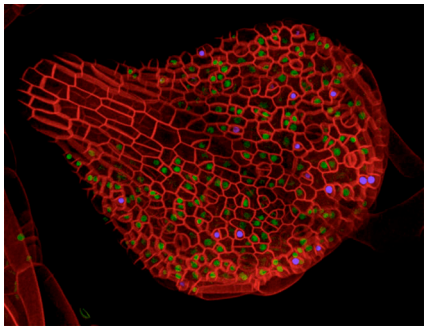

IMAGE COURTESY OF KELLI DAVIES

The transcription factors SPEECHLESS (green) and MUTE (purple) direct the formation of stomata in a developing *Arabidopsis* leaf.

I actually worry that it's going to be the best paper we ever produce because it says that plants do this—plants can polarize proteins during ACDs. So this opened up a field that we could not have gone into otherwise.

***Arabidopsis* gene names are usually quirkier, reflecting the mutant phenotype. Why so serious for BASL?**
It stands for Breaking of Asymmetry in the Stomatal Lineage. But originally we called it TGU, which just meant The Great Unknown! We thought better of that when we were about to publish it.

My very first mutant name is actually still my favorite. This mutant had only one of the two main vascular elements that run up the middle of the root. I called it LONESOME HIGHWAY.

How did your group modify chromatin immunoprecipitation to pull out the target genes that SPCH regulates in vivo?
This method is a real problem for anything that's expressed in just a few cells and transiently, like most developmental regulators in multicellular plants or animals. We'd been trying to do this for years, and SPCH is a nightmare protein to work with.

The postdoc, On Sun Lau, was trying to optimize SPCH purification right before his daughter was going to be born. It was Christmas time as well, so he wanted to get his experiments wrapped up! He had starting material for four experiments, and he simply combined all of this into one big assay. When he looked at the ability of SPCH to bind to its targets, he found it was eightyfold better instead of simply fourfold.

It turns out, if you have a very good antibody for your transcription factor, you will enrich for what you want without much background noise if you really just scale everything up. A lot.

What idea are you obsessing over at the moment?
Right now one obsession is: how do you relate polarity of individual cells to polarity of organs? In a fly wing or mammalian skin, each cell has polarity and they all coordinate, with everyone lined up in the same direction. But in the *Arabidopsis* leaf, the stomatal lineage blatantly ignores information telling it to line up. These cells specifically use some information to overcome the rules. I find that really fascinating.

"How do you relate polarity of individual cells to polarity of organs?"

MODEL TO MAINSTREAM

Is stomatal development different in plants that are more agriculturally important?
On one hand, stomata are incredibly boring. They've been two cells and a hole for four hundred million years. The exception to that arrangement is in the grasses, including corn, rice, and wheat.

In the grasses, stomata are all oriented in nice lines. They follow the leaf. And they do something that's very cool: the guard cells signal to the cells next to them, recruiting specialized helper cells. They form this four-cell complex that is really responsive, which make grasses so efficient in their photosynthesis. Grasses are the innovators.

How is stomatal development related to climate change?
The end products, stomata, are immensely influential in the climate. Every single plant you see has millions of these pores on it, and they function to take CO_2 out of the atmosphere and let oxygen and water vapor come out of the plant. The equivalent of twice the water content of the entire atmosphere gets recycled through stomata every year. Because there are so many stomata on so many plants, they're actually driving climate cycles.

There is also feedback because plants can sense their environment. If it's hot or dry or there is a lot of CO_2 around, plants will change the number of stomata they have. In high CO_2 a plant might not make as many pores. But the flip side is that water evaporation cools plants. High CO_2 and high temperatures, like recent hot summers, decimate plants because they can't move enough water to cool themselves.

What advice do you give your students and postdocs as they head out into a very tough job market?
It's heartbreaking to see really bright people who don't see a future in academic science. That's not an unreasonable fear. So, I also let them know that it's equally important that people with good scientific training and reasoning infiltrate every part of society. We should think about where else they could use this training and intellectual engagement to do something good.

1. Lau, O.S., and D.C. Bergmann. 2012. *Development*. 139:3683–3692.
2. MacAlister, C.A., et al. 2007. *Nature*. 445:537–540.
3. Lampard, G.R., et al. 2008. *Science*. 322:1113–1116.
4. Dong, J., et al. 2009. *Cell*. 137:1320–1330.
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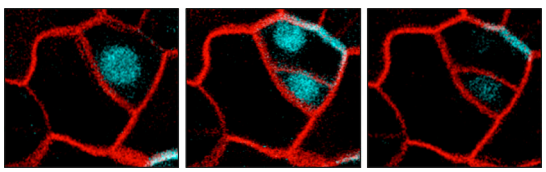

IMAGE COURTESY OF EMILY ABRASH

The polarity protein BASL (blue) switches from a nuclear to a peripheral localization during the division of a stomatal lineage stem cell.