and the mechanical strain of the plasma membrane and cell wall (Figure 1).

Undoubtedly, this recent work of Nakayama et al. [9] will influence our future models and views on developmental and environmental control of auxin-mediated growth. Previously published reports of mechanical regulation of development, for example, lateral root formation after mechanical bending of Arabidopsis roots [18,19], can now be better explained by these new insights. Moreover, although the auxin- and PIN-mediated polarity generation system is absent in animals, mechanical stress in animal cells is also known to trigger changes in the cytoskeleton [20]. It is thus possible that the proposed differential exo- and endocytosis of polarity components in response to membrane tension is a widespread phenomenon.

References

Color Vision: Retinal Blues

Two complementary studies have resolved the circuitry underlying green–blue color discrimination in the retina. A blue-sensitive interneuron provides the inhibitory signal required for computing green–blue color opponency.

Jamie Johnston, Federico Esposti, and Leon Lagnado

Our ability to detect different colors relies on color-sensitive receptors in the retina, named cones. In primates there are three types of cone, sensitive to either blue, green or red, but in most other mammals there are only two types, blue and green. Despite a limited number of cone types, we are able to detect a myriad colors; this is achieved by comparing the response from different cones. For example, the response from blue cones is compared with that from green cones to give colors along the blue-green axis.

The cells in the retina performing such comparisons are called color opponent ganglion cells. Ganglion cells that compare blue and green light can be classed as blue-ON/green-OFF, excited by blue but inhibited by green light, or they can be classed as green-ON/blue-OFF, excited by green but inhibited by blue. To understand the neural circuits by which these color-opponent ganglion cells are built it is important to realize that cones do not send visual signals to ganglion cells directly, but through a class of relay neuron called bipolar cells (Figure 1A). Depending on the type of cone that they receive inputs from, bipolar cells are tuned to be most sensitive either to blue or green light. Crucially, bipolar cells also fall into two classes distinguished by the polarity of their response to an increase in light intensity. Hence, in the retina one can find both green-ON and green-OFF bipolar cells, excited by increments or decrements in the intensity of green light.

There is good evidence that, in primates, a blue-ON/green-OFF ganglion cell is built by pooling inputs from both blue-ON and green-OFF bipolar cells [1–3]; this canonical
green-ON/blue-OFF color-opponent ganglion cells and found that the receptive fields of both tile the retina in a regular pattern. They then investigated the inputs underlying these ganglion cell responses, in particular taking advantage of the fact that the ON bipolar cell pathway is activated through a metabotropic glutamate receptor, the mGluR6. By blocking this receptor they showed that, as expected, the green-ON component of green-ON/blue-OFF ganglion cells is abolished. But paradoxically, the blue-OFF response also disappeared, indicating that it also somehow originated in ON bipolar cells.

A possible solution to this conundrum came when Sher and DeVries [4] found that an antagonist of inhibitory glycinergic receptors also abolished the blue-OFF response in ganglion cells. In the inner retina there is a subclass of amacrine interneuron that inhibits ganglion cells by releasing glycine. Could this type of amacrine cell be used to build a color-opponent ganglion cell? The problem with this suggestion is that color-sensitive amacrine cells had never been reported before [6].

Cue Chen and Li [5], who used electrophysiology to demonstrate that the retina of ground squirrel does indeed contain a population of blue-sensitive amacrine cell. By labeling these neurons during their recordings, they found that they have a distinct morphology, with dendrites ramifying in the same strata of the inner retina as the terminals of blue-ON bipolar cells. Satisfyingly, these blue-sensitive amacrine cells also stained positive for glycine transporters, providing clear evidence that they provide inhibitory input to the green-ON/blue-OFF ganglion cells. The resulting circuit explaining the green-ON/blue-OFF response is shown in Figure 1B, C. A blue-OFF bipolar cell is not needed!

**Different Pathways for Color Opponency**

If amacrine cells can be used to generate a blue-OFF response in ganglion cells, might they also be used to generate a green-OFF response? This idea seems worth pursuing in ground squirrels, because Sher and DeVries found that antagonists of the mGluR6 receptor — which cause a general block of the ON pathway — also blocked green-OFF responses in blue-ON/green-OFF ganglion cells (Figure 2A in [4]). Thus, there may also be a green-sensitive amacrine cell lurking in the retina of this animal. We can postulate that this amacrine cell would be GABAergic rather than glycinergic, because strychnine failed to block the green-OFF response [4]. It may even be that mammals have evolved different circuits for building blue-ON/green-OFF ganglion cells: the simple pathway in Figure 1A in primates, and an alternative pathway in which the signal through green-ON bipolar cells is inverted through an amacrine cell, similar to that shown in Figure 1B.

Although blue-OFF bipolar cells have not been identified physiologically (though see [7–9]), absence of evidence does not provide evidence for absence. If they do exist, it may be that they play a role in retinal processes other than classical color opponency. For instance, the retina contains a small percentage of ganglion cells that have an intrinsic sensitivity to light and very large receptive fields. These
intrinsically photosensitive ganglion cells also demonstrate blue-OFF responses generated through cones [10]. Do these signals travel through blue-sensitive amacrine cells or through the elusive blue-OFF bipolar cell? And if there are blue-sensitive amacrine cells, might there also be red- or green-sensitive amacrine cells involved in red/green colour opponency? The retina continues to surprise us.

References

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Bacteriophage Tubulins: Carrying Their Own Cytoskeleton Key

Cytoskeletal elements are well known to be widespread in eukaryotes and prokaryotes, providing important, diverse functions for cells large and small. Two new studies report that some bacteriophages encode their own tubulin homologs to facilitate phage reproduction within the host cell.

Daniel P. Haeusser and William Margolin

The last decades of research have uncovered a plenitude of prokaryotic homologs of eukaryotic actin, tubulin, and intermediate filaments in sundry organisms once thought devoid of an organized cytoskeleton [1]. To date, the identified prokaryotic tubulin super-family members consist of FtsZ, TubZ, and BtubA/B. Although the conservation of their primary sequence identity is limited to the GDP/GTP-binding motif (G box), their crystal structures show remarkable similarity between folds [2]. FtsZ is a highly conserved cell division protein found in most bacteria, several phyla of archaea, chloroplasts, and the mitochondria of certain protists [3]. TubZ is encoded within low-copy plasmids of Bacillus species, with four encoded by the chromosome, one by a plasmid, and seven members present in different phylogenetic clusters are clustered phylogenetically into two distinct groups. The first of these clusters has members present in different Clostridium species, with four encoded by the chromosome, one by a plasmid, and three by phages. One of these phages, called c-st, harbors the TubZ studied by Oliva et al. [10]. The second cluster, PhuZ, has four identified members, each encoded by a different Pseudomonas phage. Notably, the phage genomes represented in each of these phylogenetic clusters are unusually large, suggesting that phages with large genomes may benefit from encoding their own cytoskeletal protein.

The crystal structure of the monomeric GDP-bound form of PhuZ from phage 201/ß-1 of P. chlororaphis comprises an amino-terminal domain containing the G box, a long helical (H7) bridge domain and a small carboxy-terminal domain. Although it assembles into two-stranded helical filaments like TubZ, PhuZ’s structure lacks a conserved interdomain helix (H6) that is important for the polymerization of other tubulin homologs in their ability to form large microtubule-like structures, but their biological role is unknown [5].

The proliferation of metagenomics has uncovered an additional reservoir of cytoskeletal proteins for bacteriophages. Research over a decade ago identified a protein, p1, from Bacillus subtilis phage ß-29 that polymerizes into filaments that may play a role in anchoring the phage replication machinery to the cell membrane [6]. This small coiled-coil protein polymerizes in a nucleotide-independent manner, but lacks hallmarks of intermediate filament assembly [7]. More recently, researchers identified a phage actin homolog, Alp6A, in Bacillus thuringiensis phage 0305/ß-36 [8]. Alp6A forms filaments, but its function is unknown. Now, two new studies [9,10] show that some bacteriophage encode their own tubulin-like proteins. Kraemer et al. [9] report the presence of a family of proteins, named PhuZ for ‘Phage tubulin/FtsZ’, and characterize a PhuZ from a Pseudomonas chlororaphis phage. Oliva et al. [10] report a protein structurally similar to TubZ from a phage of Clostridium botulinum that also encodes botulism toxin. Each of these phage-encoded tubulin homologs assembles into GTP-dependent two-stranded helical filaments, and it is likely that they both function to organize phage DNA.