

Dwarf galaxies orbit Andromeda in a surprisingly thin plane

The Milky Way's nearby twin is a good place to look for evidence of how galaxies form.

Since 2008 the international PANDAS (Pan-Andromeda Archaeological Survey) collaboration has been availing itself of the felicitous proximity of the Andromeda galaxy to examine relics of its formation (see *PHYSICS TODAY*, November 2009, page 15). Only 2.5 million light-years (ly) away, Andromeda is a large galaxy very much like our own, encompassing 10^{12} stars within its iconic spiral-armed disk, 10^5 ly in diameter. The team searches the much larger, spherical halo of stellar and dark matter that envelops Andromeda with a wide-field camera on the Canada-France-Hawaii Telescope atop Hawaii's Mauna Kea.

An important PANDAS goal has been the completion of an unbiased census of dwarf satellite galaxies within Andromeda's halo. That task addresses the troubling "missing-satellite problem." Dark-matter computer simulations of large-galaxy formation predict many more dwarf satellite galaxies than observers have been finding.

The PANDAS detection threshold is encouraging; at Andromeda's distance,

the team can see individually almost all red giant stars within any dwarf galaxy orbiting in its halo. Still, with the census now largely complete, the team has found only 27 satellite dwarf galaxies within about half a million light-years of the disk, far too few to solve the conundrum of the missing satellites. But in the process, PANDAS has encountered a surprise that is perhaps more problematic than the dwarf shortage. An analysis of satellite motions and very precise distances, led by Rodrigo Ibata (University of Strasbourg, France), reveals that 15 of the satellite galaxies lie in a vast, remarkably thin plane through Andromeda's center—and that they appear to orbit the galaxy coherently.¹

That puzzling planarity constrains and even challenges standard scenarios of large-galaxy formation. In such scenarios, the prestellar stages are dominated by the gravitational interaction of nonbaryonic dark matter, which outweighs all the protons and neutrons in the cosmos by a factor of six. Massive dark-matter halos like Andromeda's

gravitationally attract and trap smaller ones as well as great quantities of ambient hydrogen gas. Individual small halos—the progenitors of dwarf galaxies—are presumed to be trapped independently, one by one, and therefore to enter upon separate, independent satellite orbits without regard to any preferential plane.

A preferential plane for star formation is eventually defined by the net angular momentum of the accumulated hydrogen, as dissipative gas interactions flatten and concentrate it into a spinning protogalactic disk. But satellite halos and ambient dark matter, impervious to that global dissipation, have no obvious reason to respect the disk plane. Indeed, the satellite plane discovered by PANDAS is inclined about 40° from Andromeda's starry disk. And evidence from our own galactic halo, albeit much less precise, points to a plane of satellite galaxies roughly orthogonal to the disk of the Milky Way.

An exceptional view

How is it that observers can have a more precise overall picture of dwarf-satellite orbits around Andromeda than around our own galaxy? First of all, seen from our vantage point only 2×10^4 ly from its center, the orbital motion of most of the Milky Way's satellite galaxies is predominantly perpendicular to the line of sight rather than along it. But it's only the latter—that can easily be determined with adequate precision, by spectroscopic Doppler-shift measurements.

By contrast, one gets a much better handle, albeit still only partial, on the orbits of Andromeda's satellite galaxies because, as seen from Earth, their radial and perpendicular velocity components are comparable. The outsider's view of Andromeda also minimizes selection biases. An insider's view of satellites in the Milky Way's halo is often obstructed by our galaxy's spiral arms or central bulge. In fact, to avoid biases due to similarly obstructed views in Andromeda's halo, the PANDAS search area excludes a small central patch of sky that encompasses the galaxy itself.

To determine the three-dimensional

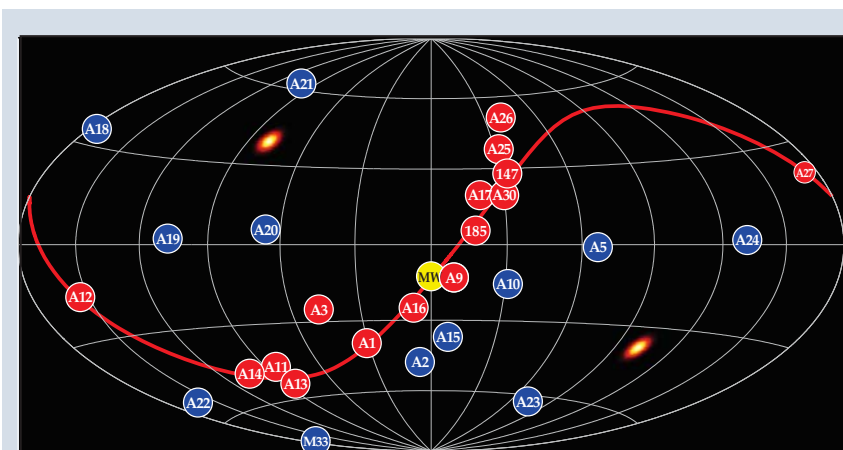


Figure 1. The 27 dwarf-galaxy satellites identified in the spherical halo enveloping the Andromeda galaxy. Their angular positions are plotted in Andromeda coordinates as an observer at the galaxy's center would see them. The equator marks Andromeda's disk plane, and the central meridian is chosen in the direction of the Milky Way (yellow). The 15 satellites shown in red all appear to be within about 5×10^4 light-years of a vast planar disk through Andromeda's center. The red curve marks the great circle of the best-fit satellite plane, and the bright blotches indicate the uncertainty of the corresponding pole positions. (Adapted from ref. 1.)

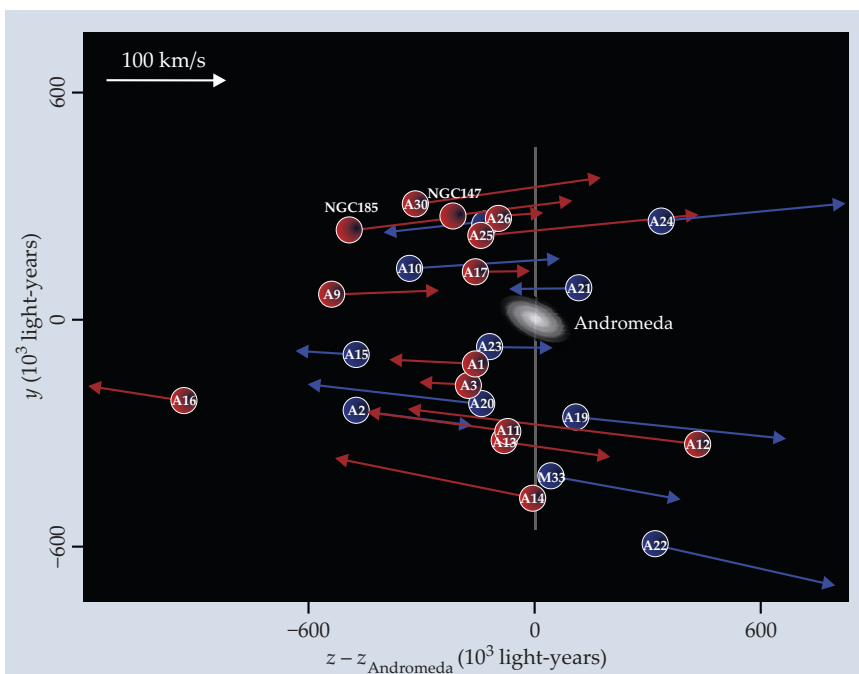


Figure 2. Line-of-sight velocity components of Andromeda's satellite dwarf galaxies, measured by Doppler shifts. Those radial velocities are indicated by the length and direction of each attached arrow. Projected two-dimensional satellite positions relative to Andromeda's center are given by distance z from Earth and northward displacement y . All the coplanar satellites (red) that lie north of Andromeda are receding, and all but two (one of them off-scale) south of the galaxy are moving Earthward. This correlation suggests that their orbits lie in the satellite plane and all have the same orbital sense. (Adapted from ref. 1.)

arrangement of dwarf galaxies within Andromeda's halo, one needs not only their positions on the sky but also distance measurements good to about 4%. The PANDAS team determined distances from observed brightnesses by taking the intrinsic luminosity of the brightest red-giant star in each halo to be close to the well-attested astrophysical maximum—about 100 times that of the Sun.

In figure 1, the 27 PANDAS dwarf satellite galaxies are plotted as they would appear on the sky to an unobstructed observer at Andromeda's center. The equator denotes the plane of Andromeda's starry disk, and the central meridian is chosen to give the direction to the Milky Way.

Satellites arrayed on a plane through Andromeda's center would appear to lie on a great circle. In the plot, the 15 satellites identified by the 3D data as being coplanar (within about 5×10^4 ly) are indeed seen to align roughly along a great circle. The 15 satellites occupy a disk a million ly wide in that plane. The team estimated that there's only one chance in a thousand that so planar a distribution over so great an expanse would be a random coincidence.

The best-fit satellite plane is inclined about 40° from Andromeda's equatorial plane. The evidence for a satellite disk in the Milky Way, by contrast, suggests an inclination closer to 90° . So if both of those very similar spiral giants do indeed have planar arrays of dwarf satellites, their very different inclinations suggest some indifference to the starry disk planes.

Figure 1 also shows the celestial position of the Milky Way as viewed from Andromeda's center. Lying within 1° of the best-fit great circle, it might be regarded as a very distant and oversized outlier in Andromeda's plane of galactic satellites. "That could well be just a coincidence," says Alan McConnachie (Herzberg Institute of Astrophysics in Victoria, British Columbia, Canada), who heads the PANDAS collaboration. "But it should be watched for in future dark-matter simulations that take specific account of our local group of galaxies. After all, Andromeda and the Milky Way do orbit each other on cosmological time scales."

Corotating orbits

If the coplanarity of the 15 Andromeda dwarf galaxies is not just a snapshot of

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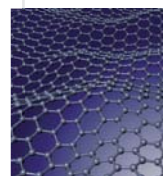
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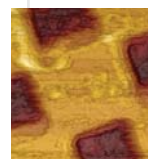
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an improbable momentary coincidence, the stability of such a special configuration requires coplanar orbits. "So we undertook the Doppler-shift measurements of line-of-sight velocity components to look for any kinematic coherence," says Ibata.

Figure 2 displays that sought-after coherence. Satellite positions, relative to the Andromeda galaxy, are plotted by distance z from Earth and transverse distance y to our north. That projection of 3D positions onto the z - y plane is particularly informative because from Earth, Andromeda's satellite plane is seen roughly edge-on, running north-south. (The interactive online version of reference 1 shows the configuration in 3D.)

The arrow attached to each satellite galaxy in figure 2 represents the direction and magnitude of its line-of-sight velocity component, corrected for the overall bulk movement of the entire Andromeda system toward the Milky Way. And it turns out that all the coplanar satellites north of Andromeda seem to be in recession phases of their orbits, while almost all those in the south are orbiting Earthward. It's what one would expect to see if they were all corotating in the same sense within the satellite plane. And this

common orbital sense is the same as that in which Andromeda's stellar disk spins. The Doppler-shift correlations, the team concludes, reduce the probability that it's all a statistical fluke to 2×10^{-5} .

Seeking an explanation

Will the new findings require major revision or just small tweaks in the standard cold-dark-matter simulations of structure formation? Such simulations exhibit a cosmological network of dark-matter filaments that serve as conduits for gas and dark-matter halos (see the article by Jeremiah Ostriker and Thorsten Naab in *PHYSICS TODAY*, August 2012, page 43). Galaxy clusters tend to form at network nodes. But the simulations and large-scale galaxy surveys suggest that the filament cross sections are too wide to account for satellite-galaxy arrays as thin as that found by PANDAS. "Perhaps," says McConnachie, "we're seeing the relics of accretion along filamentary structures that are fortuitously aligned or somehow narrowed."

Another possibility is that Andromeda's coplanar dwarf galaxies were created together by tidal interactions in the merger of two large, gas-rich galaxies. Then, however, the dwarf galaxies should contain very little dark matter.

But it's known from the internal motion of their stars that they are much richer in dark matter than is the galaxy as a whole.

"All the obvious possibilities pose problems," says McConnachie. "It remains to be seen whether models within the present standard cosmology can explain the existence of the vast, thin rotating structure we've seen next door."

Bertram Schwarzschild

Reference

1. R. A. Ibata et al. (PANDAS collaboration), *Nature* **493**, 62 (2013).

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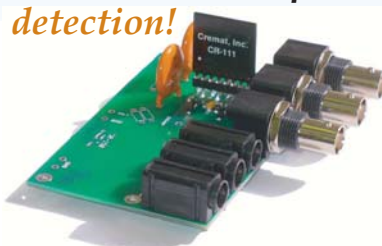
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Nanowire solar cells made efficient

An array of semiconducting nanowires can absorb nearly as much light as a thin film but at lower cost.

At first glance, an array of nanowires makes for a lousy solar cell. Their surface-to-volume ratio is huge. So when an absorbed photon produces an electron-hole pair, the charges may separate only briefly (typically driven by a p-n junction fabricated within the wire) before becoming trapped at one of the numerous defects that often reside at the surface. There, the charge carriers are more likely to recombine and thus give up their electrical energy before it can be harnessed in a circuit.

Still, a nanowire architecture has natural appeal: Scarce but highly absorptive semiconductors can be configured into photovoltaics that use far less material than those made from conventional thin films. Some III-V semiconductors, for example, have absorption coefficients a thousand times greater than silicon. But none of the earlier nanowire devices based on them have surpassed power-conversion efficiencies of 3–5%. That's well below the roughly 20% that can be achieved using conventional planar Si films (see the article by George Crabtree and Nathan Lewis in *PHYSICS TODAY*, March 2007, page 37).

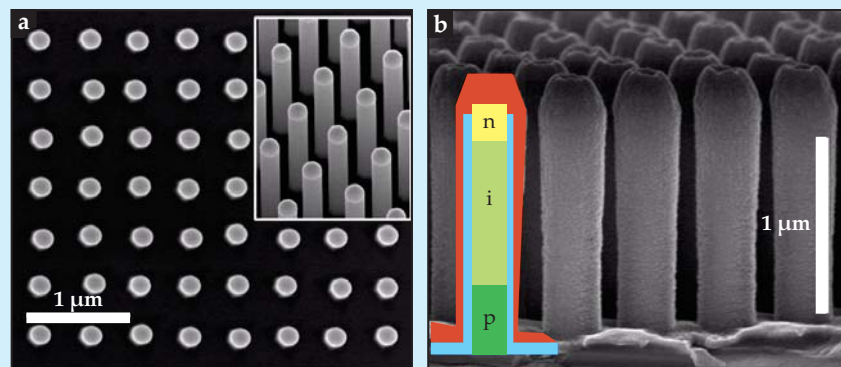
Researchers led by Magnus Borgström (Lund University in Sweden) have now shown that a judicious choice of material and refinements to its growth can dramatically improve the efficiency of a nanowire array.¹ They used the III-V semiconductor indium phosphide because it tends to exhibit slower electron-

hole surface recombination; surface states that form from dangling bonds and oxides on untreated InP simply don't trap carriers as voraciously as do, for instance, surface defects in Si or gallium arsenide.

Through modeling, Borgström and coworkers identified two key design parameters that influence device performance: the InP nanowire diameter and the length of its topmost n-doped segment, as illustrated in the figure below. The model showed that a diameter of about 200 nm would optimize the wires' absorption across the Sun's broad spectrum. And indeed, experimental tests confirmed that absorption increased with increasing diameter until it saturated around 180 nm.

To optimize conduction properties, the researchers used a 60-year-old epitaxial method, metal organic chemical vapor deposition, to synthesize the InP nanowires from the vapor phase. Specifically, they grew them as vertically stacked layers of p-doped, undoped (intrinsic), and n-doped material, an approach that enabled fine control over the length of each region. The doped regions are needed to separate the charges, but the shorter they are, the slower the electron-hole pair recombination. Because high-energy photons produce the most charge carriers near the top of each nanowire, the reduction of doped material there significantly increased current densities.

In addition, as the wires were growing, the team etched them in acid,



This array of indium phosphide nanowires, pictured in scanning electron micrographs (a) from the top and on angle, is a small fraction of the full array of 4 million nanowires that compose a solar cell epitaxially grown on a 1-mm² InP substrate.

(b) The layered p-doped, intrinsic, and n-doped segments, viewed here from the side, are enveloped by silicon dioxide (blue) to insulate individual wires from each other and by a transparent conducting oxide (red) that connects the wires to electrodes. (Adapted from ref. 1.)

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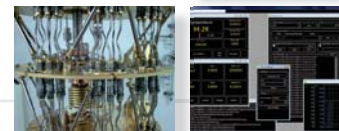
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which kept them ramrod straight and impeded any radial growth that could effectively short-circuit parts of the p-i-n junctions.

As proof of concept, the researchers built an InP solar cell, partially shown in the figure, composed of 4 million nanowires 180 nm in diameter and 1.5 μm tall, arranged in a square array in which the wires are spaced about 500 nm apart. The device converted about 14% of the incoming light into electric power—nearly triple what had been produced in earlier InP arrays and a new record for nanowire solar cells. The current density delivered by the array is nearly as great as that produced by conventional InP thin-film cells, despite the nanowires' surface packing fraction of just 12%.

The enhanced optical absorption of the device arises from the ability of the

nanowires, with diameters below the wavelength of visible light, to confine incoming rays into guided electromagnetic modes. Like miniature antennae, the nanowires concentrate incoming electromagnetic waves. Important to their success is that the spacing between wires is well matched to the wavelength at which the solar intensity peaks.

"Although the new design's efficiency remains below that of silicon cells, it's an impressive achievement that will bring validation to the nanowire community—and probably draw more people into the field," comments Stanford University's Michael McGehee. "But it's certainly not high enough to launch a product," he cautions.

There is a straightforward path to higher performance, at least in principle. One can break the Shockley–Queisser limit, which establishes the

maximum conversion efficiency of a solar cell having a single bandgap, by chemically altering the nanowires' growth to emplace multiple materials on top of each other. The different constituent materials absorb different parts of the solar spectrum. That's on the to-do list, Borgström says, noting that it's much easier to pull off in a nanowire architecture than in thin films, which can suffer more from lattice strain at the interface between materials.

"When we reach 30% efficiency, then we'll have a commercially interesting product," he says. Interesting indeed: Solar cells are already a \$100 billion industry that is growing at more than 30% a year.

Mark Wilson

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Bioelectric signaling controls tissue shape and structure

Manipulating those signals in just the right way may have applications in regenerative and cancer medicine.

The human body contains trillions of cells, all working in concert. During development, they divide and differentiate to form complex multicellu-

lar structures, and they stop dividing when those structures are complete. In the adult body, cells routinely die and are replaced by new ones. Damaged

and wounded tissues heal, up to a point. Each cell is somehow able to sense just what to contribute to an organism far larger than itself.

Biologists and biophysicists studying those processes have long focused on the molecular messengers that cells

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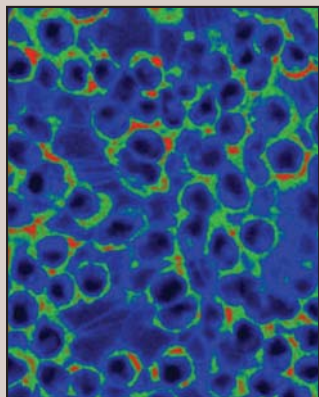


Figure 1. With fluorescent dyes whose spectral properties and spatial distribution are influenced by local electric fields, researchers can measure transmembrane voltages in cell populations (shown here), tissues, and whole organisms. (Adapted from ref. 1.)

send to one another to orchestrate their activity. More recently they've found that mechanical forces are also involved (see PHYSICS TODAY, April 2007, page 20). Now Michael Levin and colleagues at Tufts University are exploring new realms of the little-understood area of bioelectric signaling.¹ They've found that manipulating an organism's internal electric signals can alter its growth in powerful and often surprising ways. And their approach suggests that questions in areas of biology and medicine traditionally viewed as disparate—morphogenesis and development, regenerative repair, and even cancer—may really fall under a single umbrella of cell communication and information.

Electric instructions

That biological systems respond to electricity is not a new idea. In 1771 Luigi Galvani discovered that electric sparks could cause a dead frog to twitch its legs. Of course, we now know why that is: Nerve cells convey pulses of electricity that are carried by ions throughout the body, including to muscles to stimulate their movement.

In fact, all cells—not just those in nerves and muscles—can participate in electric signaling. Proteins embedded in a cell membrane shuttle hydrogen, sodium, potassium, and other ions into and out of the cell. Some of the proteins, called ion pumps, work actively (and consume energy) to move ions against

their concentration gradient. Other proteins, called ion channels, passively allow ions through, but they can close and reopen in response to various stimuli (see PHYSICS TODAY, December 2003, page 27). As a result, two cells with the same genes and membrane proteins can be in very different electric states. Together, ion pumps and channels establish a transmembrane voltage difference, V_{mem} , which can influence other cells and contribute to voltage gradients on larger spatial scales.

Since the late 1950s, researchers have identified correlations between V_{mem} and cell division. Fully differentiated cells in tissues that have stopped growing (such as nerves, muscles, and most organs) have relatively high transmembrane potentials of 50–90 mV. Cells that divide rapidly or that have more plastic identities—embryonic cells, stem cells, and cancer cells—typically have V_{mem} values of less than 30 mV. Furthermore, V_{mem} was observed to vary throughout the cell cycle in a way that appeared to be causal: Altering the ionic concentrations of cells *in vitro* to lower or raise their V_{mem} induced the cells to start or stop dividing.

But the prevailing wisdom was that it would never work to tinker with V_{mem} *in vivo*. The transmembrane potential, it was thought, was an essential component to cell health, and to alter it in a living organism would either be lethal or give uninterpretable experimental results. Levin was skeptical: "I always thought that if V_{mem} bears instructive information, then we ought to be able to dissociate that from its housekeeping functions. Remarkably, that turned out to be the case."

Viewing voltages

Before they could study the effects of changing V_{mem} *in vivo*, Levin and colleagues needed to develop the tools to do it. "For 50 years the community has focused on tools and techniques for studying gene function and chemical gradients," says Levin. "Very little had been done to help us study the role of voltage gradients." All the early measurements of V_{mem} had been done by pricking individual cells with tiny electrodes, a laborious technique that wasn't suitable for looking at V_{mem} patterns across tissues or whole organisms.

Instead, the Tufts researchers use a technique adapted from the study of electric signaling in nerve cells: fluorescent "reporter" dyes whose spectral characteristics or spatial distributions respond to local electric fields. Using a

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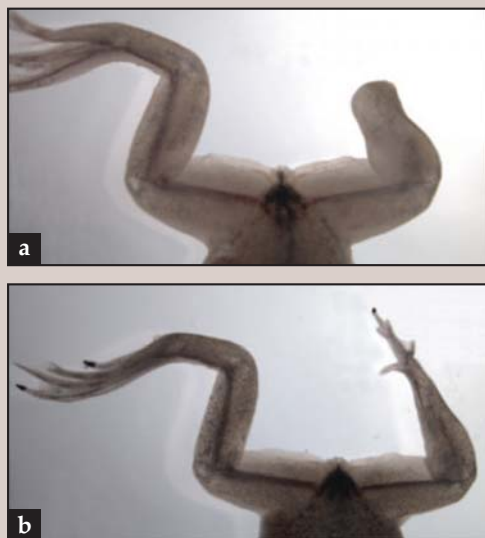


Figure 2. Frogs' legs don't normally regenerate: Cutting off the developing leg of a tadpole (a) yields a frog with a missing leg. (b) But when the tadpole is given a suitable bioelectric trigger, the missing limb can regrow. (Adapted from ref. 1.)

combination of two dyes optimized for studying resting voltages (rather than the rapidly varying nerve signals), they obtain images like the one in figure 1.

The researchers also needed tools to manipulate V_{mem} . An externally applied electric field was one possibility, but the complexity of living tissue makes it too difficult to control how the field is distributed *in vivo*. Instead, they tune V_{mem} the same way the cells do: with ion pumps and channels. They can do that genetically or pharmacologically—by treating cells with either messenger RNA or small biomolecules to change the number of membrane proteins. Importantly, they always have more than one way to induce the V_{mem} change they want to study, to make sure the effects they see are really due to V_{mem} and not to the specific reagents or ions.

A leg up

Among their findings was that bioelectrical signals often serve as triggers that set off chains of events more complex than the signals themselves. For example, tadpoles past a certain stage in their development don't normally regenerate lost body parts. A tadpole whose tail is amputated won't grow a new one, and a tadpole whose developing leg is cut off will grow into a frog missing a leg (figure 2a). But when Levin and colleagues treated the cells at the site of each amputation to lower their V_{mem} , the tail or leg was able to grow back (figure 2b).^{1,2} The regenerated appendages contained muscles that moved and nerves that were sensitive to touch, and the new legs had toes and toenails. The applied change in V_{mem} contained no

information about those structures. Nonetheless, the cells at the site of the wound were triggered to form structures that they already knew how to make, even though, without the researchers' interference, they'd never be called upon to make them.

Levin envisions applications to regenerative medicine. A long-term goal of bioengineering is to use stem cells to build new, living limbs and organs to replace those lost to injury or disease. But reproducing tissues in all their intricacy remains a difficult challenge. Finding the right bioelectrical triggers could, potentially, bypass the need for bioengineers to fully understand the structures they seek to replace.

Heads or tails

In the tail and leg experiments, body parts always grew in the right places: An amputated tail was never replaced by a leg, or vice versa. But in other experiments, the researchers found that bioelectric cues could influence not only whether a new structure grew but also what the new structure was. They discovered that a certain V_{mem} range in frogs is specific to eye formation.³ When they tuned V_{mem} out of that range at the site of the developing eyes, it kept the eyes from forming properly. But they could induce fully formed eyes to grow on any part of the frog's body by tuning V_{mem} there into that range.

Other strange results came from their experiments on planarian flatworms. Unlike frogs, planarians under natural circumstances are highly regenerative—decapitated planarians can even grow new heads. Levin and colleagues found that planarian regenera-

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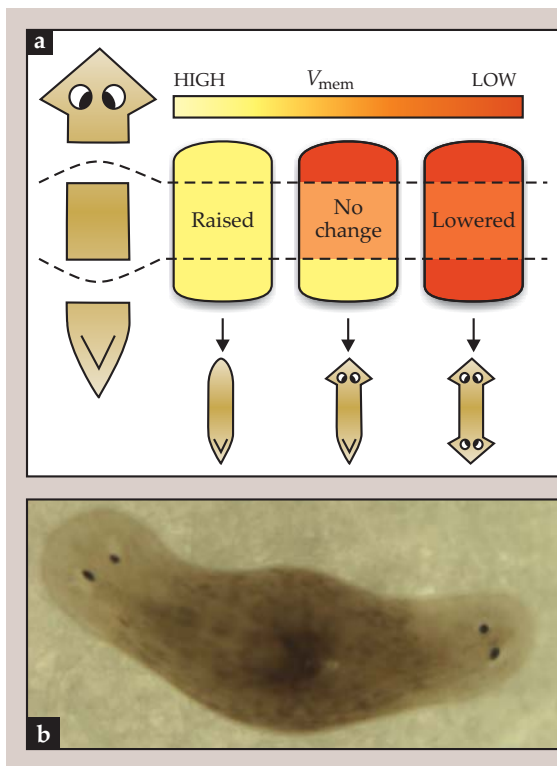


Figure 3. Planarian flatworms can regrow new tails and even new heads. The regeneration is guided by a head-to-tail gradient (a) in the transmembrane electric potential V_{mem} . Interfering with that gradient by raising or lowering V_{mem} can produce worms with two heads (b) or with none. (Adapted from ref. 1.)

tion is guided by a V_{mem} gradient from head (low) to tail (high).⁴ By manipulating that gradient, as shown in figure 3, they could produce planarians with two heads or with none. Other V_{mem} manipulations could alter the size and shape of the new heads and tails.⁵

Cancer is, in a sense, a disease of cell orchestration gone wrong—of cells losing track of what structures they’re supposed to form and instead proliferating out of control. So perhaps it’s not surprising that bioelectric signaling is involved. Indeed, it’s long been known that tumor cells have lower transmembrane potentials than healthy cells. Levin and colleagues found, in an experiment on frogs, that V_{mem} measurements could predict where tumors would form before the tumors were detectable by other means. And manipulating V_{mem} could alter a tumor’s behavior: Raising V_{mem} could, in some cases, turn cancer cells into healthy cells, and lowering V_{mem} could induce otherwise healthy cells to metastasize and spread throughout the body, just as cancer would. But there’s more to the latter effect than meets the eye: It wasn’t the metastasizing cells’ own V_{mem} that the researchers lowered, but that of other, distant cells, which then triggered the metastasis-like behavior through a combination of electric and chemical signaling.⁶

Cracking the code

Right now, bioelectric signaling is still as mysterious as it is powerful. Because large-scale V_{mem} measurements are so new, there’s a scarcity of data on how V_{mem} varies in different tissues and under different circumstances. Larger bioelectric data sets, analogous to those that already exist for gene and protein levels, could be mined for important clues.

Levin—a computer scientist by training—views multicellular organisms as sophisticated information-processing systems. In his effort to crack the bioelectric code, he’s looking to extend methods from cognitive science and artificial intelligence to systems beyond neural and gene regulatory networks. “Biology is not only ruled by chemicals and gene products,” he explains. “This new electrical layer is a fascinating and untapped field for fundamental discoveries.”

Johanna Miller

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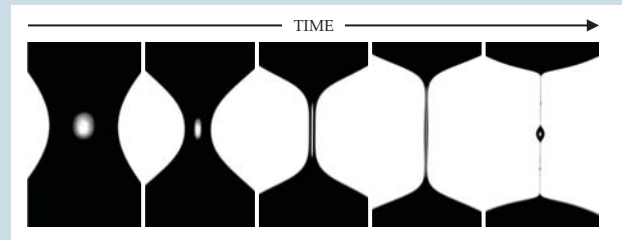


Advanced Research Systems
Tel: 610.967.2120
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physics update

These items, with supplementary material, first appeared at <http://www.physicstoday.org>.

Blood plasma not so simple after all. Blood cells make up about 46% of human blood; the rest is protein-rich, aqueous plasma. Collectively, the liquid behaves as a non-Newtonian fluid: Unlike, say, water, whose viscosity is independent of flow rate, blood becomes less viscous the faster it flows. That behavior is crucial to understanding the flow instabilities that arise near aneurysms and vasoconstrictions, and it's generally attributed entirely to the interactions between blood cells; the



plasma itself is thought to be Newtonian. Although conventional shear measurements seem to confirm that view, new results obtained with a technique known as capillary breakup extensional rheometry suggest a more complicated picture. Researchers led by Christian Wagner (Saarland University, Saarbrücken, Germany) and Paulo Arratia (University of Pennsylvania) watched as capillary forces caused a liquid bridge of plasma to stretch, narrow, and eventually break. A Newtonian fluid would have broken up while the bridge was still relatively thick and would have left behind a lone satellite droplet. But as shown in this time series of images, the plasma formed a long, thin filament whose width decayed exponentially with time. And when the filament did break, it left behind a necklace-like string of droplets, barely visible in the final frame. The implication—that the fluid is not Newtonian but viscoelastic—suggests that plasma could itself be a factor in certain blood-flow instabilities. (M. Brust et al., *Phys. Rev. Lett.*, in press.) —AGS

A twisted tale of a possibly precessing pulsar. Spinning neutron stars—pulsars—often emit jets of material along their rotation axes. The jets of the Vela pulsar, however, are extraordinary. A decade ago, a series of *Chandra X-Ray Observatory* images suggested that the Vela jet had a dynamically changing shape. But the images were erratically spaced in time and not of sufficient quality to give a reliable picture of jet evolution. Now a new *Chandra* team led by George Pavlov (Penn-



sylvania State University) and Oleg Kargaltsev (George Washington University) has collected additional images such as the one shown here—enough images to create a video of an evolving, twisting jet. Moreover, the team reports that the details of

the jet morphology are well described by a simple model that assumes the Vela pulsar is precessing with a period of 120 days and that the jet particles are ballistically emitted along the changing rotation axis. Although suggestions of precessing pulsars exist in the literature, no such pulsars have been con-

firmed. Indeed, a twisting, Vela-like jet can result from the unstable growth of density perturbations within a jet, so additional observations and analysis will be needed to confirm Vela's apparent precession. No external objects are seen to exert torques on the Vela pulsar. So if the precession picture holds up, the neutron-star matter distribution must not be spherically symmetric. Detailed analysis of the precession could provide information about how the matter is distributed. And if the Vela pulsar is indeed a massive, rapidly rotating, nonspherical object, it might be a copious source of detectable gravitational waves. (M. Durant et al., *Astrophys. J.* **763**, 72, 2013.) —SKB

Mercury levels in the South China Sea. Mercury is a potent neurotoxin. It enters the atmosphere when coal is burned and precious metals are mined. Carried by winds, Hg dissolves into seawater, where it emerges, much concentrated and to much alarm, in the flesh of large edible fish. But Hg also evaporates from seawater. To determine the net flux of marine Hg, Chun-Mao Tseng of National Taiwan University in Taipei and Carl Lamborg of the Woods Hole Oceanographic Institution in Massachusetts carried out an ambitious experiment. From 2003 to 2007, they and their colleagues made seasonal cruises across the South China Sea (SCS), taking measurements as they went. For such a study, the SCS is ideal. Not only do coal-fired plants abound in southern China, but the prevailing weather patterns are strongly seasonal. Indeed, when Tseng and Lamborg analyzed their data, they found pronounced seasonal behavior. In winter, when sea surface temperatures are low and monsoon winds are high, the SCS acts as a net sink of atmospheric Hg. In summer, when the meteorological conditions reverse, the SCS acts as a net source. Annually, the source dominates the sink: Even though the SCS makes up 1% of the world's sea surface, it accounts for 2.6% of global Hg emission. Regardless of net flux, Tseng and Lamborg found that the concentration of dissolved Hg in the SCS was at least nine times higher than in the open ocean. (C.-M. Tseng, C. H. Lamborg, S. C. Hsu, *Geophys. Res. Lett.* **40**, 167, 2013.) —CD

Threading DNA through a nanopore. Nanoscale pores are showing increasing promise as tools for DNA analysis, including size determination, folding studies, and base sequencing (see *PHYSICS TODAY*, November 2012, page 29). When threading a sewing needle, some people pass the end of the thread through the eye, while other people fold the thread first and then pass the fold through. Similarly, when a nanopore's electrophoretic forces capture a DNA molecule, the 2-nm-diameter DNA can be pulled through from one of its ends or, if the pore is wide enough, can form a fold somewhere along its length and be pulled through from there. Derek Stein and colleagues at Brown University now offer a statistical study of the fold locations in DNA passing through a voltage-biased 8-nm-diameter nanopore fabricated in silicon nitride. From the observed variations in the electrical current across the pore, the team could readily discern the positions of folds in transiting DNA molecules. The experiments show a strong tendency for molecules to be captured near their ends. A simple physical model explains the data in terms of configurational entropy: The closer the fold is to the end of the molecule, the more numerous are the molecule's possible physical configurations, and the more likely it is for one of those configurations to be observed entering the pore. Molecules, the team concludes, do not search for an energetically favorable configuration beforehand. (M. Mihovilovic, N. Hagerty, D. Stein, *Phys. Rev. Lett.* **110**, 028102, 2013.) —RJF ■