dual jets in binary black hole mergers, the simulations of Palenzuela *et al*. also have strong implications for gravitational wave astrophysics. The electromagnetic waves produced according to this scenario should be detectable, as they present a very clear energy profile. During inspiral, the dual jets lead to a particular electromagnetic structure, lasting several days and with energies proportional to the magnetic field times the orbital velocity squared. Such emission remains roughly constant over most of the inspiral, as the orbital velocity varies slowly. When the binary merges, a strong isotropic burst of radiation is emitted and the dual jets transition to a Blandford-Znajek jet with its own associated electromagnetic structure. If such a counterpart is observed, it would provide information on the location of the event in the sky. Such an electromagnetic observation could then be used in gravitational wave observations to break degeneracies and measure other astrophysical parameters more accurately, such as the Hubble constant (*12*) or the dark energy equation of state (*13*), or to test deviations from general relativity (*14*).

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CELL BIOLOGY

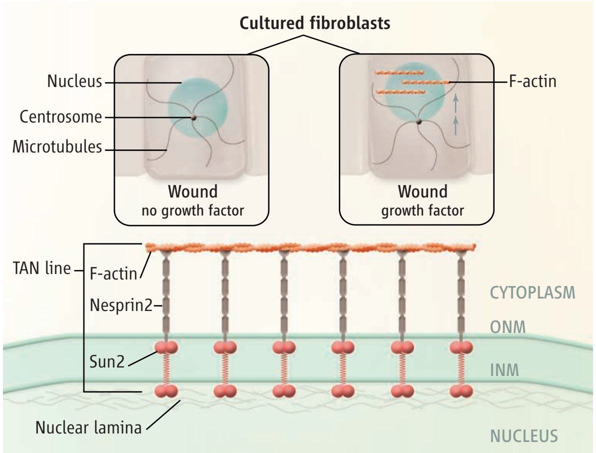
Nuclei Get TAN Lines

Daniel A. Starr

Positioning of the nucleus within a cell involves a protein complex that spans the nuclear envelope to connect actin filaments to the nuclear lamina.

The intracellular localization of the nucleus within a cell is tightly controlled and plays a central role in numerous cellular and developmental processes, including the establishment of cell polarity, fertilization, differentiation, and cell migration. Defects in nuclear movement or anchorage can disrupt development and cause disease. Many nuclear migration events involve the microtubule cytoskeleton. The nucleus is often led by the centrosome (the structure that organizes microtubules), and microtubule motors are recruited to the nuclear envelope (*1*). Other migrations use the actin cytoskeleton (*2*), but the mechanisms of actin-based nuclear migration have not been clear. On page 956 of this issue, Luxton *et al*. describe an actin network that moves nuclei (*3*).

For a nucleus to move, its structural components must connect to force-generating structures in the cytoskeleton. This is complicated by the presence of a nuclear envelope that consists of two membranes. To link the nucleoskeleton (nuclear lamina) to the cytoskeleton, outer nuclear membrane KASH proteins and inner nuclear membrane SUN proteins form bridges across the nuclear envelope (*1*). Luxton *et al*. describe structures called transmembrane actin-associated nuclear (TAN) lines, which form such a bridge (see the figure). TAN lines are made of cytoplasmic actin cables, the KASH protein nesprin2, and the SUN protein Sun2. Mammalian nesprin2 (also known as Syne-2) is a gigantic protein (greater than 750 kD) that tethers the outer nuclear membrane to the actin cytoskeleton. It consists of an N-terminal actin-binding domain, multiple spectrin repeats that likely form a fiber, and a C-terminal KASH domain (*4*). The KASH domain spans the outer nuclear membrane and interacts with a SUN protein in the perinuclear space (*5*). A SUN protein spans the inner nuclear membrane and interacts with the nuclear lamina (*6*). The importance of KASH and SUN proteins has been demonstrated by genetic experiments in model organisms (*1*). ANC-1, the ortholog of nesprin2 in *Caenorhabditis elegans*, anchors nuclei to the actin cytoskeleton, and nesprin1 and nesprin2 function redundantly to position nuclei in mouse muscles and developing neurons (*7*, *8*). Likewise, mutations in SUN proteins lead to similar developmental defects (*8*, *9*).



Moving with the SUN. TAN lines couple the nucleus to retrograde actin flow. Starved, confluent, and wounded fibroblasts are polarized after growth factor addition, which induces a rearward movement of nuclei. Microtubule networks (tan) remain centered while actin fibers (red) form on the dorsal surface of migrating nuclei. ONM and INM denote outer and inner nuclear membrane, respectively.

The major limitation of the genetic studies implicating SUN and KASH proteins in nuclear positioning is the difficulty in observing nuclear movements in situ. Thus, Luxton *et al*. used a tissue culture system where nuclear migrations can be filmed (*10*). Mouse fibroblasts grown to confluency, wounded, and exposed to a growth factor will polarize toward the wound edge. While microtubules and the motor protein dynein keep the centrosome in the center of the cell, actin retrograde flow moves the nucleus to a polarized location behind the centrosome. The advantages of this experimental system are that nuclear migration is independent of cellular migration, inducible, quantifiable, easily visualized, and amenable to disruption by small interfering RNA (siRNA) or the expression of mutant proteins. Luxton *et al*. used this system to show that nesprin2 and Sun2 are required for rearward nuclear migration in polarizing fibroblasts. Remarkably,

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nuclear migration defects caused by reducing nesprin2 expression (by siRNA) could be rescued by a "mini" nesprin2 gene that includes the actin-binding and nuclear envelope–targeting domains but lacks the bulk of the spectrin repeats. This suggests that at least for polarizing fibroblasts, the length of nesprin2 is not important.

The strength of the Luxton *et al*. study is the use of live fluorescence microscopy to examine the localization and behavior of actin, nesprin2, and Sun2 during nuclear migration in cultured fibroblasts. It was previously observed that nuclear migration required the rearward flow of actin speckles (*10*). Luxton *et al*. now describe an array of actin cables that forms on the dorsal surface of nuclei, parallel to the wound edge, within 30 min after induction of polarization. The cables moved away from the wound edge at the same rate as nuclei. Both nesprin2 and Sun2 were recruited to, and moved with, the actin cables to create TAN lines. TAN lines therefore contain all the components needed to bridge the nuclear envelope and couple the nuclear lamina to the cytoskeleton.

TAN lines have parallels to other complexes that connect actin assemblies to structural components on the opposite side of a membrane. For example, both focal adhesion complexes and the dystrophin complex span the plasma membrane, connecting actin filaments to the extracellular matrix. There are further similarities between nesprin2 and dystrophin—they have homologous actin-binding domains and spectrin repeats (*2*). In budding yeast, actin movements just outside the nucleus are coupled to rapid movements of chromosome ends (telomeres) during meiosis. A SUN protein is required for this coupling, which suggests that the assembly of TAN line–like structures at the nuclear surface might be conserved (*11*). Future studies are required to determine whether TAN lines exist in three-dimensional tissues and how broadly such structures are used in the positioning of nuclei.

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PHYSICS

Directing Light Emission from Quantum Dots

The photon emission from a semiconductor quantum dot directed by a nanoscale gold antenna could be used in quantum optics.

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Cell phones, radios, and television sets contain antennas that pick up signals carried by electromagnetic radiation and convert them into pulses of electric current. Antennas connect two very different length scales—transmission wavelengths range from centimeters to meters, whereas component wiring and circuitry is on the micrometer-to-millimeter scale. On page 930 of this issue, Curto *et al*. (*1*) take this scaling concept to the optical world, where the interaction of light with matter includes quantum mechanics as well as classical electromagnetism. They fabricate nanoantennas from gold, a metal that can develop charge oscillations in its surface layers when excited by optical radiation. These antennas allow visible radiation, which has wavelengths of hundreds of nanometers, to couple into a semiconductor quantum dot only a few nanometers in diameter, and also direct the emission.

The value of a good antenna is best appreciated when a damaged antenna cable turns a TV picture into a snow pattern. A temporary repair can be made by removing the faulty cable and sticking a screwdriver into the antenna plug. The reception will be somewhat grainy, but at least you can watch some programs. The reason for the poor picture quality is what electrical engineers call mode or impedance mismatch. The temporary antenna is not mode matched to the electronic circuits, so much of the signal fails to get into the circuits—it is reflected back into the screwdriver antenna. TV antennas are mode matched not only to the electronic circuitry, but also to electromagnetic waves, which travel through free space.

Antennas can be omnidirectional—for example, the simple dipole antenna that folds out from a portable radio. A very common TV antenna, the so-called Yagi-Uda antenna, invented by Yagi and Uda in 1926, is directional (see the figure, panel A). It can be tuned to pick up weak signals efficiently from distant transmitters. When used in transmitting mode, it can direct the outgoing beam into one direction about 5 to 10 times more efficiently than a dipole antenna.

Quantum emitters, such as atoms, molecules, and quantum dots, can also be regarded as extreme subwavelength "circuits." An electrical engineer would regard them as rather bad transmitters or receivers of radiation, because their extremely small size does not offer good mode matching to the dipole mode of the light to which they couple. Good mode-matched antennas reradiate their energy after excitation within a single cycle of the wave. Molecules or quantum dots take nanoseconds or even longer to reradiate their energy. This time scale corresponds to about 1 million oscillations at optical frequencies, and the emission is in all directions.

It is possible to fashion nanoantennas from metals such as gold that can bridge the mode-matching gap in the optical regime because they can reradiate their energy within femtoseconds (*2*). The very large oscillator strength of the antennas enables better coupling and faster response to the propagating dipole fields of free space compared to a quantum dot. Gold has a very high density of charge carriers—electrons and holes—oscillating back and forth at the so-called particle plasmon resonance. Each electron-hole pair can be viewed as a single dipole, and there are several millions of them in each nanoantenna of about 100-nm diameter.

If an atom, molecule, or quantum dot is placed into the near-field of a metallic

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