support of three different mechanisms, "all reviewed by intelligent reviewers who couldn't find anything wrong," he says.

A recent refinement by Block of Sheetz's motility assay, which makes it possible to follow the movements of single motor molecules, may help resolve the issue of how motor molecules bring about motility. Using a tool called optical tweezers, Block traps a microscopic silica bead carrying a single motor molecule on its surface with a beam of light and then deposits the bead directly on the appropriate filament where its movements can be monitored. His findings are consistent with the ratchet mechanism, but he has found some interesting differences between myosin and kinesin. The emerging picture is that kinesin spends most of its time bound to tubulin, and only a fraction of the time moving. Myosin, in contrast, spends most of its time unbound from actin filaments.

Block explains the difference by invoking the different circumstances under which each molecule must work. Myosin, he points out, is working as a team, with many heads positioned at regular intervals along an actin fiber, like oarsmen in a scull. As such, each head would do best to "flick lightly and not get in each other's way so as not to jam each other," says Block. But kinesin is more like a rope climber. It operates alone or with very few other molecules to push a vesicle along tubulin. As a result, says Block, kinesin finds itself, "clinging on for dear life to the organelle it's pushing and to the tubule it moves along. If it were to let go, the organelle would float away. To prevent that, kinesin should be unbound for a very short time."

But even that neat picture, portraying an apparent division of labor between myosin and kinesin, has now come under challenge. In the 26 March issue of *Nature*, Sue Lillie and Susan Brown of the University of Michigan Medical School at Ann Arbor report that a member of the kinesin family can substitute for myosin in delivering vesicle-bounded cargo to budding yeast cells.

Whatever their mechanism of action, the story of the molecular motors will probably take a few more twists and turns and changes of direction before it comes to a close. Mitchison predicts that many of the remaining questions will be sorted out by the end of the century, but then he thinks about it and adds, "but with the proliferation of all of these new molecules, the problem is getting more complex, not simpler."

–Michelle Hoffman

Additional Reading

M. Irving, "Biomechanics Goes Quantum," *Nature* **352**, 284 (1991).

T. A. Schroer, "Association of Motor Proteins with Membranes," *Current Opinion in Cell Biology* **3**, 133 (1991).

R. Vallee, "Dynein and the Kinetochore," *Nature* **345**, 206 (1990).

ASTROPHYSICS

Astronomers Bag Another Black Hole

Black holes once lived only in the minds of theoretical physicists and science fiction writers. Now they seem to be everywhere. It's all but certain that gigantic black holes, packing the mass of millions of stars, lurk at the hearts of some galaxies; only the gravitational force of a black hole, many researchers think, could power the titanic energy outputs of "active" galaxies and quasars or pull stars into the dense swarms seen at the centers of some galaxies. Now a new finding suggests that smaller cousins of these monsters, formed when a single massive star collapses at the end of its life, may be equally common.

In a paper submitted to the *Astrophysical Journal*, Ronald Remillard of the Massachusetts Institute of Technology, Jeffrey McClintock of Harvard University, and Charles Bailyn of Yale University report that one unseen member of the binary star system known as Nova Muscae 1991 has its companion in a gravitational grip so powerful that the mystery object must be a black hole. Other astronomers think their case is strong; says Harvard astronomer Jonathan Grindlay, "A black hole is the simplest and most economical way to explain Nova Muscae." The discovery brings the number of well-supported "small" black hole candidates to five, and it suggests that astronomers are becoming efficient hunters of these once-exotic objects.

It was only a year and a half ago, after all, when Nova Muscae first drew astronomers' attention by emitting a massive outburst of x-rays and gamma rays. Spotted by x-ray satellites including the Japanese probe Ginga, Nova Muscae remained one of the brightest objects in the x-ray sky for several weeks after the January 1991 outburst. Such an x-ray nova, astronomers believe, implies the presence of either a black hole or a superdense stellar cinder known as a neutron star; they are the only objects with the gravitational pull needed to yank material off their companions and heat it to temperatures high enough to generate an x-ray burst.

Remillard, McClintock, and Bailyn had grounds for thinking that a black hole was the more likely culprit in the outburst. Recalls Bailyn, "People looked at it and said 'My God, this looks just like A0620-00,'" another binary strongly suspected of harboring a black hole. Like A0620-00 and V404 Cygni, a probable black hole identified since then (*Science*, 14 February, p. 794), Nova Muscae's spectrum showed a huge flux of soft (low-energy) x-rays and a "tail" of higher energy x-rays and gamma rays. It also featured a bright spot at the energy—511 kiloelectron volts—given off when electrons meet and annihilate their antimatter counterparts, positrons, which are thought to be created in the high-energy environment of a black hole. Just as significant was what Nova Muscae lacked: the shorter explosions of x-rays often emitted by neutron stars. In keeping with theorists' picture of a black hole, the source seemed to have no hard surface on which infalling material could explode.

To clinch the case that the object responsible for the outburst was a black hole, though, Remillard, McClintock, and Bailyn needed something more: evidence that the mystery object was too massive to be a neutron star. Neutron stars, according to Einstein's theory of general relativity, cannot have masses greater than about three times that of the sun; such objects inevitably collapse into black holes. The upper limit of stability for neutron stars may actually be much lower, depending on how the protons and neutrons crushed together in a neutron star behave. "A more comfortable upper limit is about 2 to 2.5 solar masses," says Clemson University theorist Donald Clayton.

In their *Astrophysical Journal* paper, the trio reports that no matter which upper limit you assume, Nova Muscae is above the threshold. By using the 4-meter telescope at Cerro Tololo, Chile, to measure tiny Doppler shifts in the spectrum of the sun-like companion star, Remillard, McClintock, and Bailyn found that it circles the mystery object every 10.4 hours, at a speed of at least 400 kilometers a second relative to Earth. Drawing on a little help from Isaac Newton, they calculate that to hold the companion star in this frenetic orbit, the mystery object must be at least 3.1 times as massive as the sun—and more massive still if the companion star's orbit is tilted away from the line of sight.

That finding adds Nova Muscae to a tally of probable black holes that may grow rapidly in the future. Stanford University physicist Roger Romani estimates that as many as 500 of the x-ray emitting binaries that inhabit our galaxy may be powered by black holes. Astronomers think that when they apply their black hole tests to additional transient x-ray sources—Ginga has already found a dozen or so—the objects may prove an easy quarry. "We have just begun taming black holes," Bailyn declares. "They are becoming everyday things rather than some kind of weird, exotic beasts."

–Ray Jayawardhana

Ray Jayawardhana is a free-lance science writer based in New Haven, Connecticut.