ly lucky," Carroll reported, as all three proved active at this time.

The genes' expression patterns indicated that they help define the spots and rings. For example, in the East African butterfly, *Bicyclus anynana*, all three genes are active in what becomes the white center of the spot, while just *spalt* and *Distalless* are turned on in the black ring flanking it. And in the outer ring, only *engrailed* was active.

In contrast, in the buckeye butterfly, *Distalless*, *spalt*, and *engrailed* are turned on in both the central white spot and its adjacent ring, leaving it up to another, still unidentified, gene to set up the ring. The combinations of active genes were different yet again in two other species examined. "What we've lifted the lid on is a very flexible system," Carroll concluded.

He suggested that such flexibility in gene usage is tolerable because the butterfly has already set up the wing and other critical aspects of its body, so it can tolerate deviations in more superficial characteristics, such as the appearance of the wing decorations. What results is a rapid and continual experimentation with new eyespots and eyespot patterns, some of which persist because, in the context of entire populations, one distracts predators better than another.

Despite the progress, many questions remain about eyespot evolution. For one, Carroll has yet to identify the mutations that enabled butterflies to co-opt the same genes for so many different functions. Still, he and others are pleased with what's been learned so far. "[The work] is a very good example of comparative developmental studies and how it is now possible to do detailed studies down to the molecular level in nonmodel organisms like butterflies," notes Lennart Olsson, an evolutionary developmental biologist at Uppsala University in Sweden. "Studying later parts of development will become more common, I hope, [because] from an evolutionary perspective, later parts of development are more interesting because this is where the viable variation occurs." **–ELIZABETH PENNISI**

ASTROPHYSICS

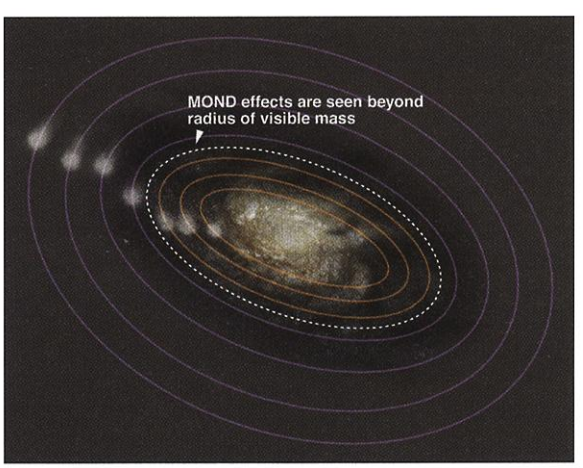
Heretical Idea Faces Its Sternest Test

Upcoming studies of the big bang's afterglow should make or break MOND, an equation that many cosmologists love to hate

When Vera Rubin began mapping massive hydrogen gas clouds that swarm around spiral galaxies like sluggish electrons around a nucleus, the astronomer at the Carnegie Institution in Washington, D.C., had a good idea of what she should find. Moving out from the galactic center, the gravitational pull of the ever-larger amount of mass within a cloud's orbit should make the cloud wheel faster and faster around the hub. But very distant clouds, orbiting beyond a certain radius that encompasses virtually all of the galaxy's mass, should chug more slowly, as the galaxy's gravitational pull diminishes with distance. Although Rubin did see the predicted rise in cloud velocity away from the center, the farthest clouds—to her astonishment—never did slow down.

To Rubin and most other experts, the explanation for this curious behavior, first noticed more than 20 years ago, had to lie in the presumption that galaxies are far more massive than meets the eye. Indeed, they say, the gravitational pull of invisible dark matter—thought to make up as much as 90% of the universe's mass—should account for the zippiness of clouds skirting the fringes of galaxies. But an alternative notion says that dark matter has nothing to do with this phenomenon. Instead, it argues that when mass is spread thinly across space, the local gravitational force—that exerted by a galaxy, say—is stronger than Newton's law of gravity predicts it should be. This gravitational fudge factor, called Modified Newtonian Dynamics (MOND), flies in the face of modern physics. But to the horror of many scientists, "it works amazingly well," says Princeton University cosmologist David Spergel.

It *was* working well, anyway, until researchers took a closer look at a new class of lightweight galaxies. There, they have found, clouds are trucking along more slowly than they should be according to MOND. "I wouldn't say it is a death blow," says astronomer Julianne Dalcanton of the University of Washington, Seattle, "but MOND is staggering and bleeding." The coup de grâce—or MOND's resurrection—may arrive after what could be a decisive test: measurements of fluctuations in the faint afterglow of the big bang, the cosmic microwave background, that should force scientists to choose between a universe dominated by dark matter and one that obeys the weird rules of MOND.



Fringe idea? Scientists hope to soon settle a debate over what keeps distant galactic clouds moving faster than can be explained by a galaxy's visible mass.

CREDIT: (PHOTO) NASA/JPL

At stake is a pillar of modern physics, Einstein's hallowed special theory of relativity. According to Newton and Einstein, gravity is a simple creature. An object's gravitational attraction, they showed, is proportional to its mass divided by the square of the distance from the object. To calculate gravitational force, all you need is the number that reflects the proportion: the gravitational constant, which holds true anywhere in the universe.

Challenging that fundamental idea about gravity, Moti Milgrom, an astrophysicist at the Weizmann Institute of Science in Rehovot, Israel, proposed MOND in 1983 as a way to explain the surprising speed of Rubin's clouds without having to resort to cramming galaxies full of invisible dark matter. Milgrom conceived another universal constant, the MOND critical acceleration. The idea is that instead of diminishing with the square of the distance, the pull of gravity—once it falls below a threshold, the critical acceleration—declines less precipitously, in direct proportion to distance. Milgrom and others have pegged a minuscule value for the critical acceleration: about one-trillionth the force of gravity we feel on Earth.

Needless to say, most cosmologists hate the idea. Not only does it fly in the face of Einstein's theory, but unlike general relativity, MOND offers no insights into how the rapidly accelerating early universe evolved, says Spergel. And cosmologists are

quick to point out that if there is no dark matter, galaxies shouldn't bend light as much as they appear to. Nevertheless, the idea has garnered adherents, including reputable scientists who didn't want to believe it at first. "I sometimes wish I hadn't gotten involved with MOND," says astronomer Stacy McGaugh of the University of Maryland, College Park, a former student of Rubin's and a specialist in charting the speeds of galactic gas clouds. "But then it showed up in my data." Indeed, for 16 years, MOND equations have explained data collected on clouds in orbit around more than 100 galaxies.

That was until a new player in the galactic lineup threw MOND a curve. Low surface brightness (LSB) galaxies are loose collections of stars weighing less than 20% of our Milky Way (no heavyweight in its own right). Applying MOND's equations, one should see gas clouds racing at speeds that—if MOND were wrong—would require a titanic dark matter halo to achieve.

When the data on LSB clouds began trickling in, MOND at first seemed on target. Then last year, Dalcanton and Rebecca Bernstein of the Observatories of the Carnegie Institution of Washington in Pasadena, California, used optical and infrared telescopes to nap the velocities of gas clouds orbiting 50 ıewly identified LSB galaxies. At a July 999 meeting of the Astronomical Society of the Pacific in Paris, they reported that the clouds were moving at velocities that could be explained by reasonable amounts of dark matter. MOND, on the other hand, could explain the cloud movements only if the galaxies were much lighter than expected—that is, if their stars were lighter than predicted by current theories of stellar evolution (xxx.lanl.gov/abs/astro-ph/9910219). Dalcanton thinks that's very unlikely. Milgrom, however, is withholding judgment until the data appear in a peer-reviewed journal. "That claim is only the latest in many, many such earlier attacks, all of which turned out to be based on errors in the data or misinterpretation," he says.

Realizing that further data on gas cloud velocities are unlikely to settle the debate, McGaugh has proposed a make-or-break test for MOND. Cosmologists think that hot bubbles of matter and light in the early universe left behind a pattern of bright and dim patches in the cosmic microwave background. Both MOND and standard theory predict that most patches of microwave light should span about 1 degree of sky as seen from Earth, an area that amounts to about twice that of the full moon. However, the competing approaches disagree on the odds of finding patches smaller than 1 degree. If the universe is mostly cold dark matter, one should expect to find many more minute patches than MOND predicts, McGaugh wrote in the 1 October 1999 issue of *Astrophysical Journal Letters*.

Measurements of the microwave background by the Cosmic Background Explorer satellite and by several recent balloon flights have mapped the 1-degree patches, but the extent of smaller patches is still in doubt because it's difficult to count them. Upcoming satellite missions in the next few years should provide a patch census accurate enough to discriminate between MOND and dark matter.

Physicist Michael Turner of the Fermi National Accelerator Laboratory in Batavia, Illinois, who makes no secret of his dislike for MOND, is confident about the final outcome: "I think that MOND will turn out to be the Bode's law of our era," he says. Bode's law, proposed by the 18th century German astronomer J. D. Titius, held that the distances of all the known planets followed from a sequence of doubled numbers: 0, 3, 6, 12, 24, etc. Adding four to each number in the sequence and dividing by 10 gives the orbital radii of all the planets out to Saturn in astronomical units. (One unit equals the distance from Earth to the sun.) It was only when Neptune and Pluto were found far from their predicted positions that astronomers recognized Bode's law for what it is: an amusing coincidence.

Although even enthusiasts are puzzled by the meaning of MOND, they aren't ready to write it off as mere coincidence. "People have taken potshots at it for 16 years," says Jerry Sellwood, a physicist at Rutgers University in New Jersey. "They haven't killed it off yet." **–MARK SINCELL**

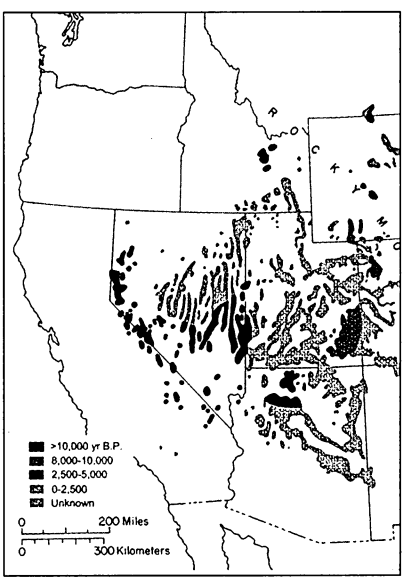
CREDIT: M. LYFORD, S. GRAY, J. BETANCOURT, S. JACKSON/UNIV. OF WYOMING

RESTORATION ECOLOGY

Returning America's Forests To Their 'Natural' Roots

New data on how North American forests looked centuries ago are fueling a debate on what ecologists should aim for when restoring ailing ecosystems

The flames licked high into the sky above a stand of Utah junipers in the foothills of Wyoming's Bighorn Mountains. Phil Shepard stood for a while admiring his handiwork, which ended up incinerating 283 hectares of Tensleep preserve. No arsonist, Shepard, an ecologist who manages the preserve for The Nature Conservancy, had set the fire to beat back the junipers that had overrun lush grassland and to thin out a ponderosa pine forest that had accumulated dead and diseased wood. One lightning strike could have touched off a devastating blaze, he says, if his group had not struck first.



Advances and retreats. New data on the spread of Utah juniper have prompted scientists to rethink restoration goals in parts of the Western United States.

Shepard views the Bighorn's overgrown forests as more than a fire hazard, however. The juniper and pine, he says, are driving out aster and other plants that flourished before people of European descent and their livestock settled this rugged land more than a century ago. The controlled burn was part of an effort to turn back the clock on the preserve's ecosystem. And Shepard isn't alone in his nostalgia for a wilderness of yore: Plenty of other ecologists view prescribed fires and other interventions, such as selective logging, as essential stratagems for repairing ailing ecosystems. The goal, as Interior Department Secretary Bruce Babbitt puts it, is to restore these lands "to a presettlement equilibrium."

The need to reduce the risks of widespread conflagration in the nation's forests is adding urgency to such efforts: Last month, the U.S. Forest Service reported that about 17 million hectares of national forest in the western United States are at "high risk of catastrophic wildfire," a fragility brought on by years of zealous efforts to stamp out natural fires. The forests "have become a tinderbox ready to explode," says the service's Chris Wood. Last year, federal agencies torched 931,000 hectares, more than twice the average annu-