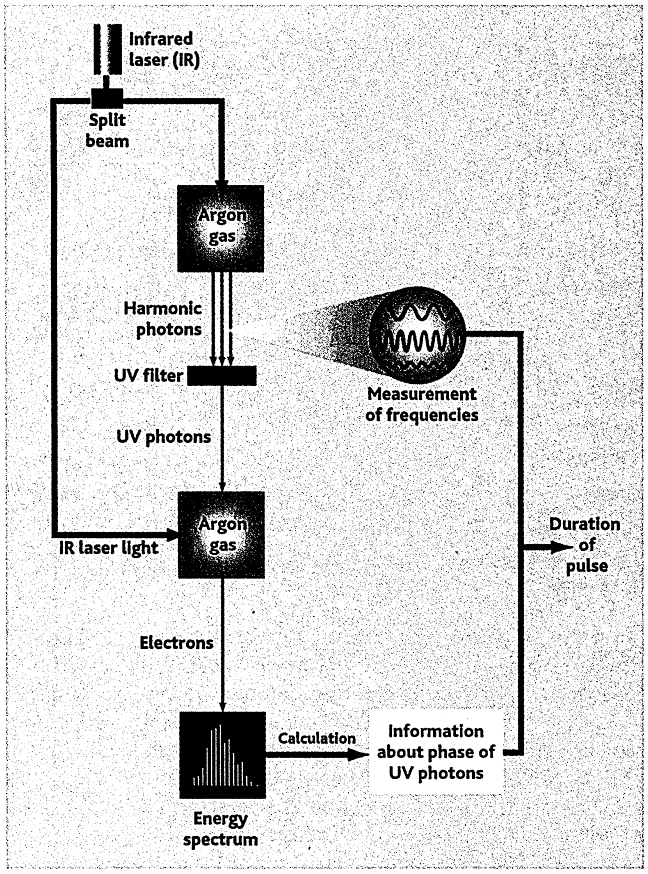


Quick study. A novel experimental setup allows researchers to spot attosecond pulses for the first time.

way to spot such fleeting bursts: Electronic detectors are too plodding and simply record a blur of photons. "How do you know what you've got? That's been the struggle," says Corkum. Muller and his colleagues managed the feat not by detecting the photon bursts themselves but by tracking their ability to ionize atoms in a nearby gas jet—a technique that Corkum says "works very well."

Generating the short pulses in the first place is a comparatively simple task. Quantum-mechanical calculations show that if light waves spanning a broad range of frequencies are brought together under the right conditions, they can interact to produce an ultrashort pulse. Muller and his colleagues—including teams led by Philippe Balcou at the National School of Advanced Techniques (ENSTA-École Polytechnique-CNRS) in Palaiseau, France, and Pierre Agostini at the Saclay Research Center of France's Atomic Energy Commission—create this broad range of frequencies by a technique Corkum dreamed up in the mid-1990s (*Science*, 4 August 1995, p. 634). Starting with a short-pulse infrared (IR) laser that fires pulses lasting just 40 femtoseconds (a femtosecond equals 1000 attoseconds), the researchers split these light pulses and steer one portion toward a jet of gaseous argon atoms; the second portion is used in a later detection step. The intense light ionizes the atoms and generates an oscillating electric field that drives the freed electrons away from their parent atoms and then back again at high speed. Some of the surging electrons smash into their parent atoms, releasing energetic short-wavelength photons across a broad range of frequencies. Most of the photons cancel one another out as the peaks of some line up with the troughs of others, but a few of them—those at odd harmonic intervals of the initial laser light—survive.

Physicists have long calculated that these surviving photons would be produced in a staccato of attosecond pulses. But to confirm that's what they had, Muller's team needed to do two things. One was to get a precise accounting of frequencies produced and the amount of each one, both of which they could track easily with a device called a spectrophotometer. The other was to determine their relative phase, that is, whether the waves and crests marched in lockstep. "That's the key," says Muller. With the phases and frequencies in hand, the team could mathematically work out the pulse durations.

To get those phases, the French and Dutch researchers came up with a novel scheme. First, they used mirrors to filter out all of the harmonic photons except a band in the ultraviolet (UV) range. They trained the UV beam into a second gas jet of argon atoms. At the same time, the team zapped the gas with the second half of the original infrared laser beam. Under the double bombardment, the argon atoms absorbed photons and kicked out electrons. Using standard detectors, the researchers recorded the number of the electrons and their energy levels. Then they varied the phase of the incoming IR photons by passing them through a glass window that slightly slowed their progress. The changes in the IR phase altered the photons' ability to kick out electrons at different energy levels. By measuring how the distribution of electron energies changed and by crunching some numbers, the researchers were able to work out the phases of both the IR and UV photons that must be present at each position—information that enabled them to confirm the brief but notable lifespan of their record-setting pulses.

Muller and Corkum say the next race will be to use the pulses to track the blinding dance of electrons around nuclei, which are too fast for even today's femtosecond lasers to capture. As well, they say researchers will undoubtedly want to slice out single flashes from the attosecond pulse trains and try to shave each pulse down to just 10 or so attoseconds each, the theoretical limit for the methods now being used. "It's something we're working on. But it's still really science fiction at the moment," says Muller. Until this week, so were 220-attosecond pulses.

–ROBERT F. SERVICE

NEUROBIOLOGY

Bee Dance Reveals Bee's-Eye View

Imagine a driver asked to judge the distance traveled by keeping track of the number of buildings, signs, and lampposts whizzing by. Now ask that driver to tell a friend how far to go based on those visual cues. That's exactly what honeybees do, says Harald Esch, a neurobiologist at the University of Notre Dame, Indiana. For years, bee biologists have argued about whether the dance that honeybees perform when they return to the hive communicates anything more than the general direction of the nectar source. Now Esch and his colleagues have settled this question by tricking a foraging honeybee into communicating the wrong information to its hivemates. The work, reported in the 31 May issue of *Nature*, shows that "bees really are getting [distance] information from the dances," says Thomas Seeley, a biologist at Cornell University in Ithaca, New York. The work also confirms that the bee measures distance in terms of "optic flow," the stream of visual cues encountered along a flight.

Over the past several years, experiments have suggested that honeybees know how far they've gone by how much they've seen—and not, as many researchers had

CREDIT: (RIGHT) MARCO KLEINHENZ

Bee reckoning. The tunnel's pattern alters the bee's visual "odometer."

thought, by how much energy they've expended on their trip. In a key experiment, Mandyam Srinivasan and Shaowu Zhang, neurobiologists at Australian National University in Canberra, Jürgen Tautz of the University of Würzburg in Germany, and their colleagues tested this idea by training bees to fly down tunnels with different patterns painted inside. They found that the bee danced longer than it should have after flying through a semicheckered tunnel that gave the bee the sense of moving past many, many objects. If the tunnel was lined with horizontal stripes, which had no vertical boundaries to signify an object being passed, the bee's dance was too short. These experiments, coupled with earlier work by Esch, strongly indicated that the bees use the passing landscape to click off the meters.

In this new work, Srinivasan, Zhang, and Tautz teamed up with Esch to see whether a bee actually communicated its misperceptions to other bees. "It's another in a series of very cleverly designed experiments," comments Mark Frye, a neurobiologist at the University of California, Berkeley. The researchers first set up a tunnel lined with a complex pattern, then trained bees leaving the hive to fly through the tunnel to get to a feeder on the other side. They videotaped the bee's dance when it returned and calculated the distance communicated. The bee danced as if it had traveled 72 meters instead of 11, the true distance. "The bees felt like they had gone a greater distance," says Frye.

The researchers then stationed themselves 35, 70, and 140 meters away from the hive for 2.5 hours and counted how often bees from the hive flew up to them in search of food. About three-quarters of the 220 bees approached the 70-meter spot looking for nectar—the distance communicated in the dance. Based on these results, says Frye, "there is now no question that the way honeybees communicate distance depends on what they see." —ELIZABETH PENNISI

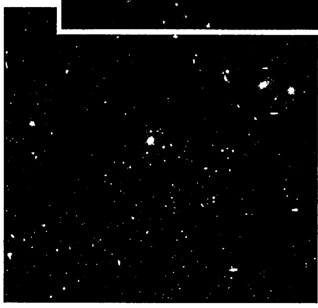
ASTROPHYSICS

Radical Gravity Theory Hits Large-Scale Snag

La fin du MOND c'est arrivé—perhaps. For nearly 2 decades, modified Newtonian dynamics (MOND), a heretical theory that alters some properties of gravity to eliminate the need for dark matter, has survived one astronomical observation after another—and even gained strength in the process. But now, physicists at the Institute for Advanced Study in Princeton, New Jersey, have shown that the theory is deeply at odds with observations of galaxy clusters, suggesting that MOND is in trouble.

"I take it very seriously," says Stacy McGaugh, an astrophysicist at the University of Maryland, College Park, who has supported the theory. "It's a real problem for MOND."

On one level, MOND is an attractive idea. Astronomers have long been troubled by the motion of matter within galaxies; peripheral stars and clouds orbit the galactic center faster than Newtonian (and Einsteinian) laws of gravity dictate. Most scientists explain the discrepancy by assuming that galaxies are surrounded by a halo of invisible matter, but in 1983 Mordechai Milgrom of the Weizmann Institute of Science in Rehovot, Israel, created MOND as an alternative explanation. He altered the standard rule for gravity so that slowly accelerating objects feel a slightly stronger gravitational pull than Newton's laws dictate. That gives the outer edges of galaxies an extra little tug, causing them to move faster. The tweak reproduced the motion of the galaxies with high precision, without the need for dark matter.



A matter of scale. Although MOND succeeds in individual galaxies such as M100, it fails in galaxy groups like the Virgo cluster.

CREDITS: (TOP TO BOTTOM) NASA; DIGITIZED SKY SURVEY/PALOMAR OBSERVATORY/STSCI

"It's a simple and clear prediction that matched the observations well," says Anthony Aguirre of the Institute for Advanced Study. "It does seem to succeed miraculously well." On another level, however, MOND is a very unappealing theory, because mathematicians haven't been able to meld it with the framework of general relativity.

It should come as no surprise that scientists have been taking potshots at MOND for years; however, the theory has survived them surprisingly well (*Science*, 28 January 2000, p. 572). Indeed, a missing "peak" in microwave-background data (*Science*, 28 April 2000, p. 595) was briefly seen as a surprising source of support for MOND, although the peak has since been found (*Science*, 4 May, p. 823). But the tide might now be turning.

Aguirre and his colleagues have analyzed x-ray data from the ROSAT, ASCA, and BeppoSAX satellites to determine the temperature of matter in galaxy clusters. Much of that matter takes the form of x-ray-emitting gas, whose temperature depends on its density, pressure, and acceleration. Those factors, in turn, reveal information about what governs the clouds' motion—dark matter or modified gravity. It turns out that MOND fails the test: The observed temperatures look nothing like what would be expected in a MOND-controlled cluster. The data "disagree very strongly with MOND's prediction," says Aguirre. "MOND is not a viable alternative to dark matter in clusters."

"There is a conundrum," Milgrom admits, although he notes that he has known about problems with galaxy clusters for some time. Additional unseen matter, like the once-unknown x-ray-emitting gas throughout the cluster, might account for the discrepancy, he says. "There is always room for yet-undetected matter," he says.

To Aguirre, this is an unsatisfying solution. Unseen matter, he points out, smacks of the very problem MOND was designed to avoid. Soon, observations of the cosmic background radiation—precise measurements of a third "peak" in the data—may well put the matter to rest once and for all. "Oh, I hope so," says McGaugh. "I really do hope so." In the meantime Milgrom holds fast to MOND, although he admits the possibility that his theory will one day be falsified. "As its inventor, I would like it to be a revolution, but I look at it coolly," he says. "I will be very sad, but not shocked, if [the answer] turns out to be dark matter."

—CHARLES SEIFE

ASTRONOMY

Deep-Space 'Filament' Shows Cosmic Fabric

Astronomers peering back to the early days of the universe have detected the primordial building blocks of galaxies. These cosmological Lego blocks—older and smaller than any detected before—are arranged in an elongated filament. The observations support a popular theory of cosmic evolution in which matter first collected into a network of thin filaments and later coalesced into clusters and superclusters.

The so-called cold dark matter theory was proposed some 20 years ago to explain the structure of the universe. It holds that in the earliest days after the big bang, exotic