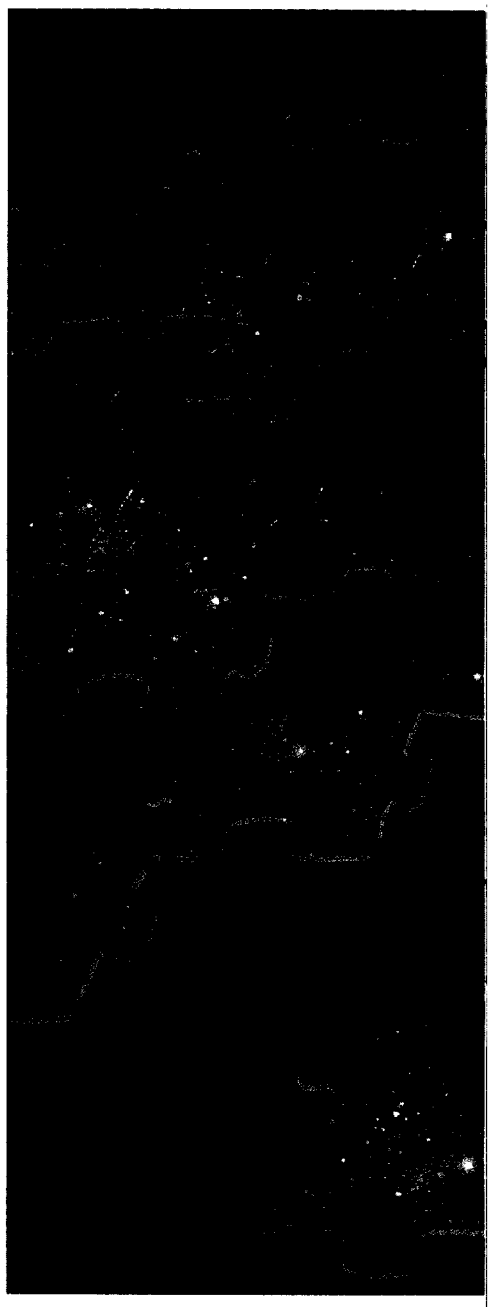
THE New Dark Age OF Astronomy

Astronomers can't answer a simple question that a child might ask: What is the universe made of?

by Marcia Bartusiak



A diverse assortment of telescopes points at the heavens and gathers data that, more often than not, clarify and extend our accepted model of the universe. But at times a finding pops up that generates new challenges. It is a piece of the cosmic puzzle that never quite fits in. The greatest moments in astronomy are often foreshadowed by these nagging uncertainties, annoying loose threads that hang off the tight weave of a long-established theory.

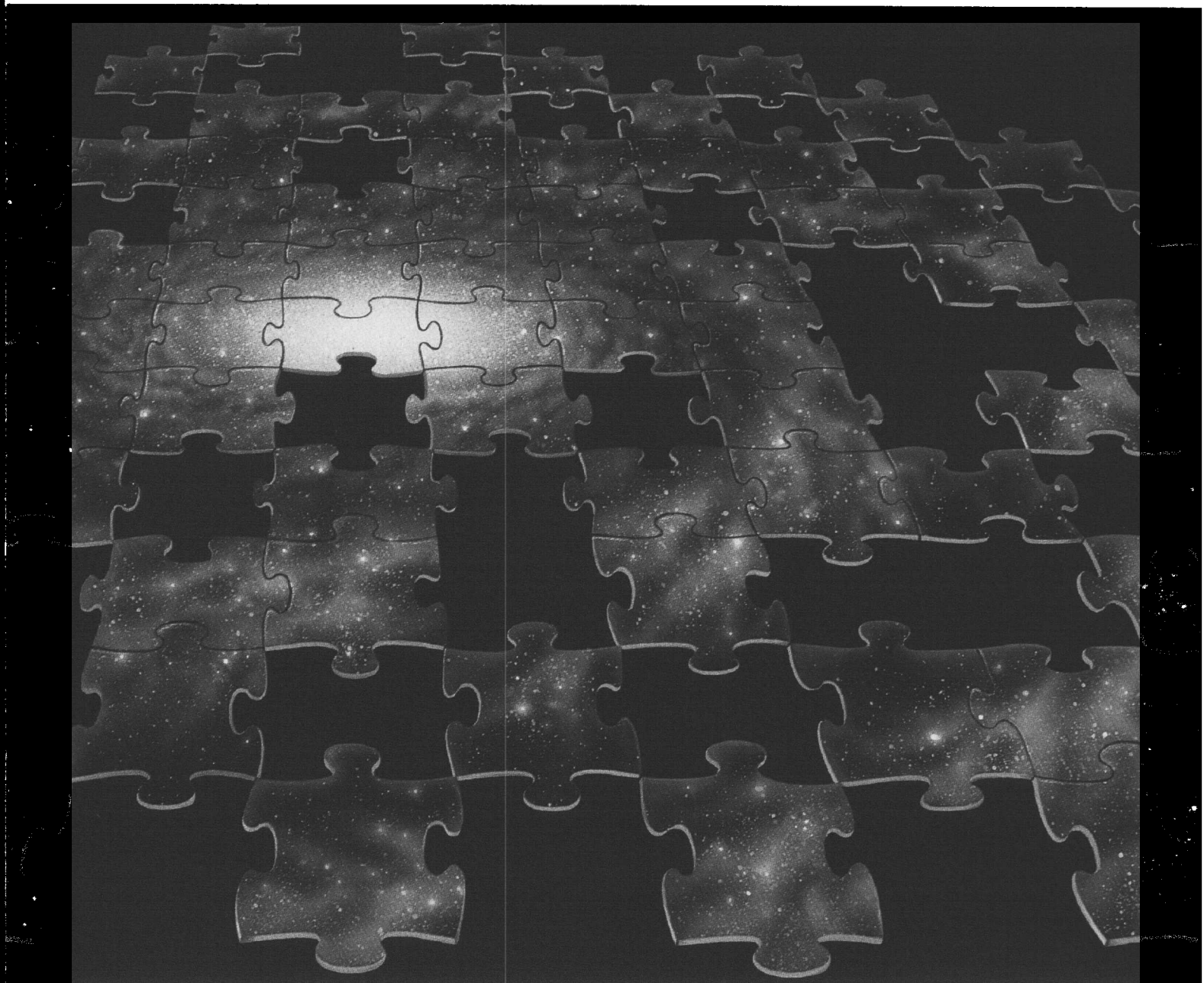
Such crises in astronomy periodically wax and wane over the centuries. Take epicycles, for example. Ptolemy, the noted second century astronomer and geographer, proclaimed that the universe was flawless and unchanging, with a motionless Earth poised prominently in its center. The sky was an intricate maze of wheels within wheels – epicycles – that soundlessly revolved around God's central creation, humanity.

Ptolemy's vision held sway for some 1,400 years. But as planetary movements were studied with more and more accuracy, this complicated picture began fraying at the seams. In 1543 the Polish clergyman Nicolas Copernicus offered a new paradigm, a novel way of looking at old, familiar facts. He moved the Sun to the center of the solar system. Ptolemy's universe at last crumbled in 1609, when German astronomer Johannes Kepler discovered that planets trace elliptical orbits, thus making epicycles irrelevant once and for all.

A few centuries later astronomers were baffled by wispy, spiral-shaped patches of light in the nighttime sky that could not be resolved into individual stars. For decades they heatedly debated the true nature of these enigmatic spiral nebulae. Aided by the largest telescope in its day, the massive 100-inch reflector atop California's Mount Wilson, Edwin Hubble finally proved in the 1920s that the misty objects were separate "island universes." Our home galaxy, the Milky Way, was but one among billions of other galaxies spread throughout space. The cosmos, cozily centered on us for so long, opened up a millionfold.

And now another mystery is tugging at observers' shirtsleeves. Just four decades ago astronomers were convinced that a final tally of the universe's contents was nearing completion. They knew that hydrogen and helium originated some 15 billion years ago in a burst of elemental cooking that took but minutes during that primordial explosion known as the Big Bang. More complex atoms, such as oxygen, carbon, and nitrogen – the stuff of life – emerged later after the birth of stars, whose fiery interiors construct these weightier elements.

More recently, however, clues have been swiftly emerging that a dark, hidden universe lurks beside this luminous cosmos so long studied with telescope and spectroscope. No one expected this turn of events. It's thrusting astronomy back into a "dark age." Each and every galaxy in the universe could be but an inconsequential raft floating within a much vaster sea of unseen matter.



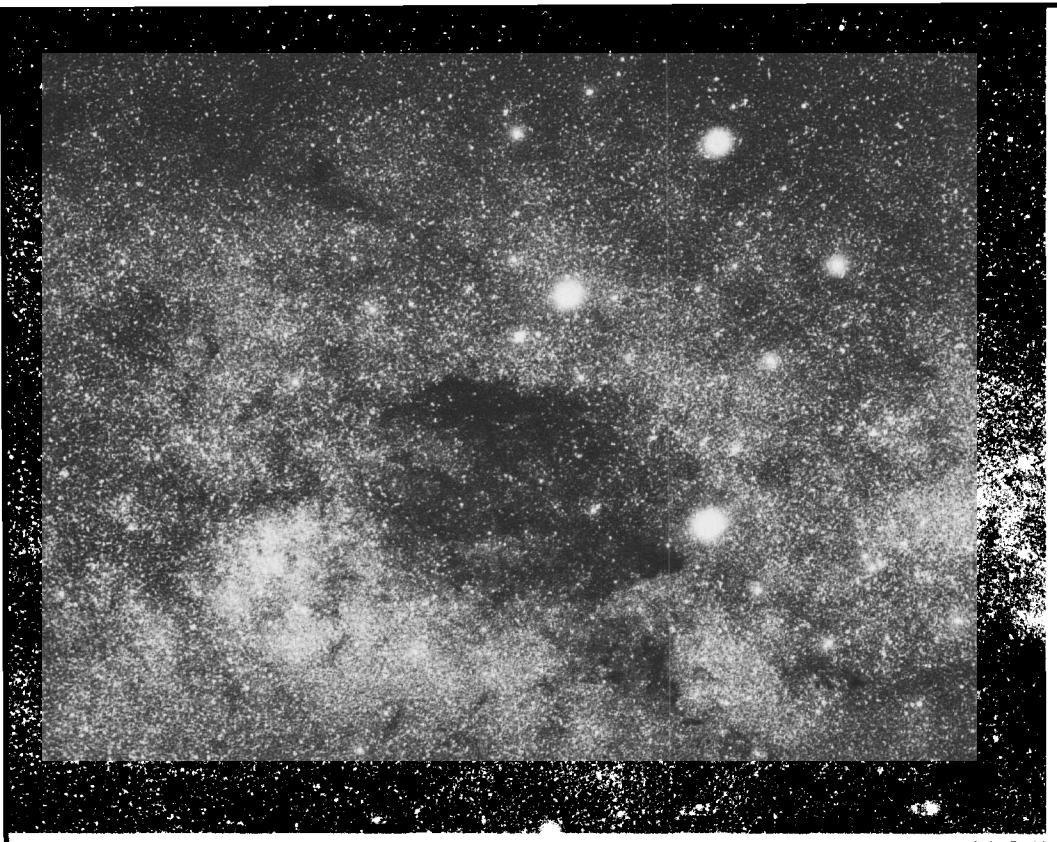
Lynette Cook

This material emits not one glimmer of detected light, yet it could account for more than 90 percent of the universe's mass. "A 4-year-old might ask the simple question, 'What is the universe made of?' And we can't answer it," says Fermilab cosmologist Rocky Kolb.

A great deal hinges on figuring out the answer to this straightforward question. Determining the composition of this ocean of dark matter has the potential to alter our views of the cosmos: how galaxies were born; how fast the universe is expanding; and whether our universe will end in a fiery conflagration or limp forever outward to icy nothingness.

The first hint that something was amiss in the inventory of the universe's contents actually appeared more than 60 years ago. In 1933 Caltech astronomer Fritz Zwicky examined the motions of galaxies within the famous Coma Cluster. He noticed that the galaxies were moving rapidly within the cluster. After adding up all the light emitted by the galaxies, he realized that there was not nearly enough visible, or luminous, matter in the form of stars and nebulae to gravitationally bind the speeding galaxies to one another. But the cluster still remained very much intact. Zwicky had to assume that some kind of unseen matter – a missing mass – pervades the Coma Cluster to provide an additional gravitational glue. Something else was out there, a dark, nameless matter that outweighed the luminous mass ten times over.

The mystery of the dark matter didn't make much of a splash during those Depression years. Most astronomers believed the dilemma would disappear once theorists figured out the motions of galaxies in more detail. By the 1970s, however, the problem was brought closer to home when radio and



Luke Dodd

Dark nebulae do *not* constitute the universe's dark matter. When astronomers inventory the universe's visible contents, they include dark nebulae such as the Coalsack in the southern constellation Crux.

optical astronomers revealed that the problem wasn't just in clusters.

After studying hundreds of individual spiral galaxies, Vera Rubin and her colleagues at the Carnegie Institution of Washington established that the outer parts of these galaxies were rotating around their galactic centers as fast as the inner parts, in direct violation of Kepler's laws. Indeed, the spiral galaxies are spinning so fast that they have to be embedded in vast spheres of additional material. Otherwise, their outer stars would zip completely out of the galaxy, like a discus cast out of the hand of a whirling athlete. "Nature has played a trick on astronomers, for we thought we were studying the universe," says Rubin. "We now know that we were studying only the small fraction of it that is luminous." But what makes up the rest of it?

For many astronomers, the solution is obvious: The dark matter, they say, is simply composed of ordinary matter, but in a form that is difficult to spot. They're spurred on by a fascinating concurrence; all the visible and estimated dark matter taken as a whole just about matches the maximum number of "baryons" or ordinary matter – the protons and neutrons that make up atoms – that scientists think were forged in the first second of the Big Bang. That's a telling match-up, strong evidence that the dark matter can be made out of familiar but not-easily-detectable celestial objects, such as extremely faint white-dwarf stars, black holes, or "failed stars" called brown dwarfs. According to this scheme, 10 percent of the ordinary matter born in the Big Bang turned into objects that shine brightly like the glowing lights on a Christmas tree, while the other 90 percent remains hidden in a dark halo surrounding most galaxies.

Searches for this great pool of matter have been underway in recent years, and initial results are encouraging. Earlier this year astronomers reported the first signs that a multitude of burned-out white-dwarf stars might be surrounding our galaxy. These so-called MACHOs (astronomers' whimsical acronym for MAssive Compact Halo Objects) could account for a sizable chunk of the Milky Way's missing mass.

But that's only part of the dark matter story. The latest and most fashionable cosmological theories suggest that the dark matter comprises, not ten times as much mass as the luminous stars and galaxies, but up to a hundred times more. Cosmologists believe this extra mass arose when the universe experienced a fleeting moment of superacceleration at its birth – a period of "inflation." Instead of a continual and steady expansion, the cosmos allegedly tore outward briefly like a spaceship on warp drive, leading to a flood of additional particles and radiation.

But there's a catch: No one has yet detected the presence of such huge amounts of matter in the universe. For the moment, this idea is like a theoretical wish, and many astronomers are not yet convinced that inflation ever happened.

If this extra stuff truly exists though, it can't be ordinary matter. The Big Bang couldn't have cooked up that many protons and neutrons. That turns the dark matter mystery, once the sole province of astronomy, into a special challenge for particle physicists. They must come up with new and exotic species of particles to serve as this additional cosmological dark matter.

A particle known as the neutrino (Italian for "little neutral one") is a popular candidate, and for good reason: it's already known to exist. But no one yet knows for sure whether these slippery particles – they can pass through entire planets like ghosts – have any mass, at least enough substance to serve as the cosmologists' dark matter. Physicists at the Los Alamos National Laboratory have recently announced that they've found evidence for a massive neutrino in a particle accelerator experiment, but this result awaits confirmation.

Meanwhile, theoretical physicists are continually dreaming up new particles. And if these particles prove to be more than hypothetical, they might be ideal for explaining the cosmological dark matter. For instance, in dealing with certain aspects of the strong nuclear force (the force that keeps atomic nuclei from flying apart), physicists have predicted the existence of the axion, a particle that

was named after a laundry whitener. Even though an axion is calculated to be 100 billion times lighter than an electron, the particle would be so insubstantial that trillions could be stuffed into every cubic inch of space around us. But, taken over the entire cosmos, all those axions would add up to some substantial matter.

There are also a number of particles that pop up in equations as theorists try to unify nature's various forces. In these schemes, every particle already known to exist has a partner. The Z particle has its Zino, the W particle its Wino, the photon its photino, and the quarks their squarks. Collectively, these have come to be known as WIMPs, for Weakly Interacting Massive Particles. Each would be roughly as heavy as ten or more protons, yet still, like the featherweight axion, be rudely indifferent to ordinary matter.

Physicists take this idea very seriously. Indeed a number of groups have constructed special instruments in hope of capturing one of these exotic dark matter particles. Others are sifting through the debris of high-energy collisions in particle accelerators, which can briefly recreate the conditions of the early universe. Some physicists think the footprints of WIMPs have already turned up in the ashes of such collisions.

Which avenue is most fruitful – searching for MACHOs or WIMPs – will be known only in hindsight. Will the dark matter consist solely of a hidden armada of white- or brown-dwarf stars? Or is there an extra component of exotic elementary particles spread throughout the cosmos as well?

If the dark matter is largely made up of undetected particles, uncovering the dark matter mote could be as momentous as the discoveries of the electron, proton, and neutron — maybe more so. Such a particle, unlike the stuff that makes up people, suns, and planets, would be the predominant substance of the cosmos. "It would be the ultimate Copernican revolution," says Bernard Sadoulet, director of the Center for Particle Astrophysics at the University of California in Berkeley. We'd have to come to terms with the possibility that the very atoms in our bodies are but a minor constituent in the universe's essential makeup.

Tremors surround us. Zwicky first noticed that a large component within a cluster of galaxies was missing; decades later, the rumbles got louder when Rubin deduced that spiraling galaxies were immersed in a dark, unnamed material. Do these tremors portend a bigger quake ahead, a temblor that wrenches the center of our universe again, just as the findings of Copernicus and Hubble once did? A few adventuresome theorists are even suggesting that the bulk of the dark matter will be explained in another way altogether, by new physical theories.

I have this dream that there will be a sort of Sherlock Holmes event," says Princeton astrophysicist James Peebles. "Someone will look at this great pyramid of evidence that is building up and exclaim. 'Yes, Watson, I think I see it. By Jove, that must be it.'"

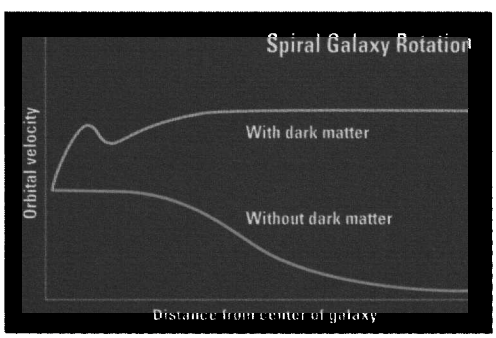
We eagerly await that momentous occasion. □

Tony and Daphne Hallas

If dark matter didn't exist, galaxy clusters such as the great Virgo Cluster (above) would fly apart.

Marcia Bartusiak is an adjunct professor of science journalism at Boston University. This article is based on her most recent book, Through a Universe Darkly (HarperCollins/Avon), which chronicles the dark matter search.

Astronomers know that dark matter surrounds spiral galaxies such as NGC 2997 (right) because the outer regions rotate around the galactic center just as fast as the inner regions, in seeming violation of Kepler's laws.



ASTRONOMY: Phil Kirchmeier

Anglo-Australian Telescope Board