# INTO THE DARKNESS

*Illustration by Ray Crane, Charles Hayden Planetarium*

**Out there lies a dark universe, hiding from our view.
But is this really true?
Scientists are scrambling
to solve the mystery of the beyond...**

Halfway through this century astrophysicists were on the brink of drafting a complete and compelling history of the universe's contents. The saga began some 15 billion years ago with the creation of hydrogen and helium in a burst of elemental cooking that took but minutes during that primordial explosion impishly known as the "Big Bang." More complex materials, such as oxygen, carbon, and nitrogen — the stuff of life — later emerged with the birth of stars, whose fiery interiors are hot enough to construct these weightier elements.

In 1951 Giorgio Abetti, a noted Italian solar physicist, remarked that astronomy was approaching the conception of a harmony of creation...and "of a unity of matter in all the visible world." A comprehensive tally of the universe's ingredients seemed on the verge of completion.

Yet even as Abetti was making his assertion about a unity of matter with such supreme confidence, clues were emerging that a dark, hidden universe lurked beside the luminous cosmos so long studied with telescope and spectroscope. No one expected this turn of events. Astronomy was crossing a threshold: As if caught in the inky shadow of a solar eclipse, astronomy's concerns suddenly had to shift. Long involved with the universe's light — the glimmering array of stars and galaxies — observers now had to peer into the celestial darkness, bleak and cold.

It's true that cashes of material, previously invisible, were often uncovered by astronomers. Infrared telescopes were needed to spot protostars gestating within thick cocoons of dust and gas scattered about the Milky Way. And radio telescopes revealed the existence of immense reservoirs of interstellar molecules, such as water and ammonia, once thought impossible to assemble in space. Yet all these concealed inventories turned out to be a type of matter very familiar to us — a part of the universal recipe. This dark, hidden universe may be different.

One of the very first hints that something was amiss in astronomy's accounting of the universe's contents emerged nearly 60 years ago. The man responsible was Fritz Zwicky, a physicist and astronomer with the California Institute of Technology who had an uncanny ability to propose certain ideas years before their time (he predicted the existence of the tiny neutron star more than 30 years before the first one, beeping away as a pulsar, was discovered). In 1933, Zwicky examined the motions of galaxies congregated within the famous Coma cluster, a particularly rich assembly of galaxies located some 300 million light-years away, and noticed that the galaxies were moving within the cluster at a fairly rapid pace. Adding up all the light emitted by these galaxies, he came to realize that there was not enough visible, or luminous, matter in the cluster to gravitationally bind the speeding galaxies to one another.

The situation seemed paradoxical. Under the standard laws of celestial mechanics, with the galaxies in the Coma cluster buzzing around so nimbly, the cluster should have been breaking apart, but it was very much intact. It was as if space-shuttle astronauts ignited all the engines and rocket boosters on their spacecraft at full power, yet found themselves unable to lift off from the Earth. Shuttle engineers might be forced to conclude that the Earth suddenly and inexplicably had more mass (and consequently a stronger gravitational field) to keep such things as shuttles from flying off too easily. Similarly, Zwicky had to assume that some kind of unseen matter pervaded 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. In his report to a Swiss journal, Zwicky referred to this unseen ingredient as *dunkle Materie*, or dark matter, demonstrating that matter, although invisible, can still be detected through its gravitational clout.

The mystery of dark matter didn't make much of a splash during those Depression years. Some astronomers thought it was just an exotic but not too bothersome property of clusters; others believed the dilemma would disappear once theorists figured out the motions of galaxies in more detail. But, by the 1970's, the problem was brought closer to home when radio and optical astronomers began to reveal curious rotations in both the Milky Way and nearby spiral galaxies. Indeed, the dark matter issue turned into one of the most active concerns in astronomy as soon as Vera Rubin and her colleagues at the Carnegie Institution of Washington D. C. obtained a veritable arsenal of measurements (since 1978, the Carnegie group has analyzed the rotations of more than 200 galaxies).

Rubin established that spiraling galaxies are spinning so fast that they had to be embedded in vast spheres of extra material to keep the stars from zipping completely out of the galaxy, like a discus cast out of the hands of a whirling discus thrower. Rubin helped prove that dark matter was not just a quirky property of clusters, as Zwicky first discerned; it surrounded individual galaxies as well.

"The idea was certainly in the air," notes Princeton astrophysicist, P. James E. Peebles, "but Vera's measurements were very influential in causing people to pay attention to this effect."

Her data suggests that 90 percent or more of the universe's mass is playing an awfully good game of hide-and-seek with earthly detectors. This unknown material doesn't seem to absorb or emit any kind of x-ray, radio, or light waves that can be detected so far. What could dark matter possibly be?

For many astronomers, the simplest solution would be that dark matter is composed of just ordinary matter, but in a form that is difficult to detect. They are perfectly happy with the idea that dark matter consists of a host of extremely faint dwarf stars, black holes, or Jupiter-like planetoids called brown dwarfs, objects just short of the mass needed to sustain a stellar nuclear fire in their cores. Searches for this great pool of brown dwarfs are underway with infrared and optical telescopes but, so far, without success. Some doubt they will ever be found.

"For one thing, our theories of how the visible stars formed have a hard time making all those other objects," says David Seckel, a theorist with the Bartol Research Institute in Delaware. "Also, from what we know about galaxy formation, it is hard to create a universe filled with galaxies if dark matter is like ordinary matter."

The latest and most fashionable cosmological theories suggest that dark matter is composed of something more inherently elusive — exotic, hard-to-catch particles. For a while, a particle known as the neutrino was a popular dark matter candidate, and for good reason. Neutrinos are already known to exist (the Big Bang spewed out hordes of them), and they can speedily pass through buildings and planets as though they were ghosts. But, for the moment, no one yet knows whether neutrinos are anything more than mere spots of energy. They must have some mass to serve as dark matter.

But neutrinos are just the first in a long line of particle suspects. Theoretical physicists are continually coming up with new particles as they postulate various theories. And if these particles really exist, they might be ideal for explaining 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 whimsically named after a laundry product. Perhaps more than a trillion times lighter than an electron, the axion 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 of theorists who are trying to unify nature's various forces. In their schemes, every particle already known to exist should have a partner. The Z particle, for example, would have its Zino, the W particle its Wino, the photon its Photino, and the quarks their squarks. The lightest and most stable of these predicted particles could serve very well as dark matter. Collectively, these candidates have come to be known as WIMPS, for Weakly Interacting Massive Particles. Each would be roughly as heavy as 10 or more protons, yet still, like the featherweight axion, be terribly indifferent to ordinary matter. They'd snub it.

The National Science Foundation has taken this idea seriously enough to set up a Center for Particle Astrophysics at the University of California, Berkeley, in order to design and construct a special detector that could capture an exotic dark matter particle. Joining them in this hunt are more than a dozen groups around the globe. Each research team has staked out a different theoretical territory, betting that its own custom-made detector has the best chance of finding bona fide evidence of a dark matter universe.

Which avenue is most fruitful will be known only in hindsight. Will dark matter consist of ordinary brown dwarfs, or will it be a herd of objects far smaller? If it is particle in nature, finding this dark matter mote could be as momentous as the discoveries of the electron, proton, and neutron, maybe more so. Such a dark matter particle, unlike the stuff that makes up people and planets, would be the predominant substance of the universe.

"It would be the ultimate Copernican revolution," says Bernard Sadoulet, director of the Center for Particle Astrophysics. In the 16th century, the Polish churchman and scholar, Nicolaus Copernicus, displaced humanity from the center of the universe by suggesting that the Earth revolved around the Sun. Nearly four centuries later, the American astronomer Edwin Hubble continued the process by proving the Milky Way galaxy is but one in a myriad of galaxies populating the universe. Now we must come to terms with the possibility that the very atoms in our bodies are but a minor constituent in the universe's essential makeup.

No matter which dark matter candidates prove to be the one, physicists and astronomers would be overjoyed to secure the first firm detection. That occasion, if and when it occurs, would be as momentous as the Nobel Prize-winning discovery in 1965 of the universe's microwave background, the fossil echo of the Big Bang itself.

And if such a discovery were to happen tomorrow? "I'd retire," says David Seckel with a laugh. "I'd retire."

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## The Making of *The Mystery of the Dark Matter*

The making of any Planetarium show is a special challenge. Although the story of dark matter is a hot topic and makes for a good mystery, it was a particularly tricky story for the Museum to produce.

Since dark matter is something that can't be seen or detected in any wavelength (radio, x-ray, gamma ray, etc.), how were we going to support the story visually?

We decided that one of the important educational objectives of this show was to illustrate that, in science, you often have to study what you *can't* see by observing its effects on what you *can* see.

Taking wind as one example, we show a panorama of trees with their branches swaying. We point out that even though we can't see the wind, we know it's there because we can observe its effect on the visible trees.

We used another metaphor to show that what we observe is often not all there is. We ask the audience to imagine they are visitors from another planet traveling to Earth for the first time. It is night, and as they approach Earth, they see a sprinkling of lights. We Earthlings know that these lights are just suggestive of the city that contains them, but would extraterrestrials know that?

In the case of dark matter, the study of galaxies has suggested that what could be seen — luminous matter — was not all there was. These visuals were easy for us: Galaxies are recurring characters in our shows, and we know how to do them well whether they are clustered, rotating, or stationary.

The challenge was to offer a simple explanation of how the study of galaxies led to the conclusion that over 90 percent of the universe is made up of the mysterious substance called dark matter.

Fortunately, we got some help from Dr. Vera Rubin, whom we met during the "interview the experts" phase of the project. Dr. Rubin is responsible for pivotal research in the study of dark matter, and even more important to us, she spoke clearly, concisely, and simply about an incredibly complex subject, and serves as an excellent role model for girls. As we illustrate in the show, Dr. Rubin's fascination with the stars began around age 10, when she spent many a night staring at the slowly changing sky.

*The Mystery of the Dark Matter* was a challenge to produce, but with the help of Dr. Rubin, we have created a fascinating story well worth a trip to the Planetarium.

*by Dorothy Crawford*
*Manager, AV Production*

The Mystery of the Dark Matter *is currently showing in the Charles Hayden Planetarium through the summer of 1992.*