

Without an as-yet-unidentified material called dark matter, clusters of galaxies wouldn't hold together.

## WHAT IS THE UNIVERSE MADE OF?

# In the dark

By Alexandra Witze ■ Illustration by Nicolle Rager Fuller

In ancient times, listing the ingredients of the universe was simple: earth, air, fire and water. Today, scientists know that naming all of that, plus everything else familiar in everyday life, leaves out 95 percent of the cosmos's contents.

From the atoms that make up an astronomer, to the glass and steel of a telescope, to the hot plasma of the stars above — all ordinary stuff accounts for less than 5 percent of the mass and energy in the universe. “All the visible

world that we see around us is just the tip of the iceberg,” says Joshua Frieman, an astrophysicist at the University of Chicago and the Fermi National Accelerator Laboratory in Batavia, Ill.

The rest is, quite literally, dark. Nearly one-quarter of the universe's composition is as-yet-unidentified material called dark matter. The remaining 70 percent or so is a mysterious entity — known as dark energy — that pervades all of space, pushing it apart at an ever-faster rate.

“Dark” is an appropriate adjective, as

scientists have little insight into where dark matter and dark energy come from. But figuring out dark matter would illuminate what holds galaxies together. Figuring out dark energy might help reveal the universe's ultimate fate (see Page 30).

It's little wonder that scientists regard the identities of dark matter and dark energy as among today's biggest astronomical puzzles.

### A different matter

Dark matter made its debut in 1933, when Swiss astronomer Fritz Zwicky measured the velocities of galaxies in a group known as the Coma cluster and found them moving at different rates than expected. Some unseen and large

amount of “*dunkle Materie*,” he proposed in German, must exist, exerting its gravitational effects on the galaxies within the cluster.

Astronomer Vera Rubin confirmed dark matter’s existence in the 1970s, after she and colleagues had measured the speeds of stars rotating around the centers of dozens of galaxies. She found that, counterintuitively, stars on the galaxies’ outer fringes moved just as rapidly as those closer in — as if Pluto orbited the sun as quickly as Mercury. Rubin’s work demonstrated that each galaxy must be embedded in some much larger gravitational scaffold.

Ever since, other lines of evidence have strengthened the case for dark matter. It resembles ordinary matter in that it interacts via the well-understood gravitational force; that’s why it affected Zwicky’s and Rubin’s galaxies. But scientists know that dark matter is not ordinary; if it were, it would have affected ratios of chemical elements born in the early universe and thus thrown off the abundances of such elements observed today.

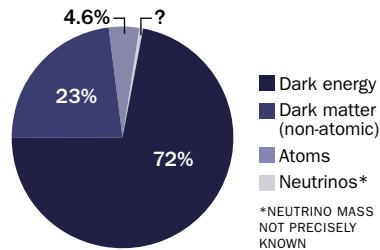
The leading candidate for a dark matter particle is the vaguely named “weakly interacting massive particle,” or WIMP. Such particles would be “weakly interacting” because they rarely affect ordinary matter, and “massive” because they must exceed the mass of most known particles, possibly weighing in at as much as 1,000 times the mass of the proton. But nobody has yet definitively detected a WIMP, despite decades of experiments designed to spot one.

Results from dark matter experiments are mixed: One group in Italy claims to see a WIMP signal seasonally, with more WIMPs hitting detectors as the Earth moves into a stream of galactic dark matter debris, and fewer when Earth moves away. But other researchers haven’t been able to confirm those results. Recent reports from other experiments, including one buried in Minnesota’s Soudan mine, hint that WIMPs might be lighter than theorists had expected, on the order of 10 proton masses (*SN: 8/28/10, p. 22*).

The sensitivity of many long-running

**Mostly unfamiliar** The stuff that makes up people, planets, stars and interstellar gas accounts for just under 5 percent of the universe. The rest is made of mysterious entities dubbed dark matter and dark energy.

#### Mass-energy content of the universe



SOURCE: WMAP

experiments is now improving to the point that WIMPs and other candidate particles should be either spotted or ruled out in the near future.

#### Mysterious forces

Spotting dark matter may prove to be easier than understanding dark energy, whose mysteries make scientists feel like mental wimps.

Albert Einstein unknowingly ushered dark energy onto the stage in 1917, while modifying his new equations of general relativity. Einstein wondered why gravity didn’t make the universe contract in on itself, like a balloon with the air sucked out of it. He thus made up a “cosmological constant,” a fixed amount of energy in the vacuum of space that would provide an outward push to counter gravity’s inward pull.

In 1929, though, Edwin Hubble solved Einstein’s problem by reporting that dis-

tant galaxies were flying away from each other. The universe, Hubble showed, was expanding. It had been zooming outward ever since the Big Bang gave birth to it.

Einstein happily ditched his cosmological constant, but in 1998 astronomers showed that it should have been recycled rather than trashed. That year, two research teams reported their studies of distant supernovas. These exploded stars can be calibrated to serve like standard light bulbs, shining with a particular brightness. The scientists reported that many distant supernovas were dimmer than expected, even accounting for an expanding universe. It was as if someone had quickly moved the light bulbs into a more distant room. The universe was not only getting bigger — it was doing so at an accelerating rate.

Something funny was going on, giving the cosmos a repulsive push. So Michael Turner, a cosmologist at the University of Chicago, dubbed the thing “funnyenergy” at first, before settling on “dark energy.”

More than a decade later, scientists still don’t have a concrete clue to what dark energy is (*SN: 2/2/08, p. 74*). Theorists have done their best to explain it, putting forward ideas including a seething “vacuum energy” created as particles pop in and out of existence, and “quintessence” — named after Aristotle’s postulated fifth element — that changes its strength depending on its place or time in the universe.

Meanwhile, observers have spent the last decade dreaming up ways to

probe dark energy from the ground and in space (see Page 32). In particular, precision measurements of many distant galaxies could help pin down the nature and distribution of dark energy. A new camera, optimistically called the Dark Energy Survey, will see first light this autumn at the Cerro Tololo Inter-American Observatory in Chile. Real light — insight into the dark — may take some time. ■



In this false-color image of galaxies colliding, the majority of the mass (blue) is separate from most normal matter (pink), direct evidence of dark matter.