Figure 1.5. The Hubble "Ultra-Deep Field" reveals thousands of galaxies within a pinhead of the sky a mere twentieth of a degree across, a tenth the angular size of the full Moon. A few big bright ones are relatively nearby, while the faintest stretch out to billions of light-years away. The farther they are, the faster they move away from us, the first clue that the Universe was created in a "Big Bang." Though their number seems overwhelming, galaxies such as these represent less than 1 percent of the mass-energy of the Universe. NASA, ESA, R. Windhorst (Arizona State University), H. Yan (Spitzer Science Center, Caltech).

smeared out, density of mass (including the mass equivalent of energy) that is required to roll out spacetime with no bends whatever, to make it, in a weird multidimensional way, "flat" (such that Euclid's famed plane geometry actually works).

Add up the stars and the stuff in the spaces between them, and it totals to just under a percent of that needed. More mass is indicated by Big Bang theory, which predicts how primitive hydrogen atoms combined to create a variety of light chemical elements. Much, if not most, of this matter seems to be in the form of hot gas that lies between the galaxies of large clusters, and even between clusters, where it is observed with X-ray telescopes. Some is matter left over from galaxy formation, while much was also ejected from the cluster's members by stellar explosions. Or so it's thought. Summarizing the various predictions and observations gets us close to 5 percent of the flatness requirement.

Then descends the shroud. Our Galaxy, its stars revolving around the center under the influence of their combined gravity, is spinning too fast for what we see. Galaxies in clusters orbit around the cluster's centers under the influence of *their* mutual gravities, but again, they move faster than expected. There must be something out there with enough of a gravitational hold to do the job, to speed things up, but it is completely unseen. *Dark matter*. It surrounds galaxies, pervades their clusters. We have no idea what constitutes it. Rather, there are *many* ideas, but none that can be proven. Add it all up based on the amount of mass needed to yield dark matter's gravity, and lo, one finds another 20 percent, getting us up (once the numbers are rounded off) to a quarter of that required to unfold the Universe, but still not enough.

To resolve the issue (and to add to the mystery at the same time), look deeper at the expansion. Modern telescopes, imagers, and above all, knowledge, have allowed cosmologists to measure the expansion rate to distances of billions of light-years, allowing us to look far back into time. We might expect a slowdown of the expansion as the combined gravity of everything in the Universe acts to hold it back. Velocity and redshift are indeed seen *not* to be quite in direct proportion to each other. Instead of showing a slowdown, the observed variance reveals the opposite, a surprising speedup! The expansion is getting ever faster. Any acceleration requires energy, which from its mass equivalent yields the missing 75 percent. Within the uncertainties of the data, the Universe is flat! But we have even less of an idea where this energy comes from than we do about the nature of dark matter. So to dark matter, add *dark energy*. Either that or something is terribly amiss with our concept of gravity.

We seem almost to be back to primitive times when we first looked up to the stars to wonder what they are. We are still wondering just as hard, perhaps not about stars as such, but about the stuff that surrounds them, which surely has a role in making them, and that then plays a role in making us. So we keep wondering and exploring. And as we reach out in our attempts to understand them all, from planets to galaxies, they in turn reach back to us to aid in our quest.

Heaven's Touch

Return to the outpost in deep space from which we observed the Milky Way. The scenery is quiet, serene, strikingly beautiful. Nothing seems to happen. Floating in the void we feel isolated, just as we would back on Earth where our own planet dominates us and our thoughts. What do these stars have do with us? We cannot reach them. Their great distances make it likely that no spaceship ever will. And there is no evidence that anyone out there—if there is anyone—has ever, or will ever, come here. All the connections we have with the distant cosmos seem to be from beautiful and benign starlight, which allows us to admire and study the Universe, but never to reach out and touch it.

Similar concepts of alienation extend to near space, to our Solar System. The Sun warms us with its light and heat, but otherwise we pay it little heed. One hundred million miles away—a hundred times the solar diameter, ten thousand times Earth's diameter—it seems otherwise not to affect or bother us. The Moon and planets, going through their once-mystifying movements (which we now fully understand from gravitational and orbital theory), are pleasing and fun to watch, but again they appear to have no direct bearing upon our own small world. Though we have gone to them, imaged them up close, have even landed upon them out of curiosity and a yearning for exploration, we could as easily have left them alone, as they do us.

Or do they? The story of discovery over the past century or more has starkly revealed that such isolationist views are the reverse of reality. Our senses are limited, and our life on Earth short compared with the flow of celestial time, both of which veil many of the remarkably varied ways in which the heavens directly interact with us. Indeed, life itself would be impossible without all these direct interactions.

Begin by standing at the beach to watch the water go up and down in synchrony with the position and phase of the Moon, all powered by gravity from a satellite a quarter million miles away, the cycle modified by the far more distant Sun. Not just for the watching, tides are a part of the fabric of life, perhaps even in part responsible for its creation. They—the tides—are on Earth, but not of Earth, as their production lies in the heavens, which reaches out to touch our world.

Through the tides, the Sun barely reveals its power. Northerners will tell you more, about the shining lights in the night sky, the northern lights that hang, that flow, that shoot luminous cannonballs across the sky, all caused by the pieces of atoms shot at us by the Sun, accelerated toward us in association with raging solar magnetism. Far more than causing pretty lights, solar storms disrupt our planet's magnetic field, make compasses go awry, break the electronics that ride aboard billion-dollar satellites, and can even make our lights go out. When the storms subside over long periods—decades—our Earth chills. Without the Sun's magnetic effects, it's even conceivable that terrestrial life could never have begun. More invisibly, billions of subatomic particles pass harmlessly through us each second from the deeply buried nuclear furnace that powers sunlight. The Sun, Helios, indeed reaches out to touch us in ways that we are only beginning to understand.

Move on to the planets, the Earth's brethren that orbit the Sun, from Mercury close in, to Uranus and Neptune far away, the Earth number three. All are satellites of the Sun that were created along with it some four and a half billion years ago. As does the Moon, they affect us through their gravity. Too far away to cause tides of any measurable sort, they instead act to pull on the whole Earth and alter its orbit. Over the aeons, the distance between the Earth and Sun changes first in one direction, then in the other, as does the orbital oblateness. Couple that with a 26,000-year wobble in our rotation axis caused by the Moon and Sun acting on an equatorial bulge that comes from terrestrial rotation, and our seasons and climate gradually change from variances in solar heating. Ice ages may be a consequence.

Benign though they may seem, the planets even come to visit, their attentions sometimes quite unwelcome. They were born through successive collisions of smaller bodies (built from dust grains) that orbited the primitive Sun. The process, however, was far from 100 percent efficient, resulting in a large amount of leftover debris that consists of the rocky-metallic small asteroids mostly between Mars and Jupiter and the icy comets that mostly reside beyond the planetary system. Acting as "dirty snowballs," cometary bodies measured in tens or hundreds of kilometers across lie in two great reservoirs. One, a flat but thick plate beyond Neptune, is made of comets that were too thinly spread to assemble into a planet. The other, holding comets that were kicked out of the planetary system by the giant outer planets, may extend halfway to the nearest star. If caught in a long, looping orbit, a comet can get close enough to the Sun so that its ices turn to gas, which, with the release of dust, produces the graceful tails iconic to astronomy.

Collisions among asteroids coupled with the gravitational effects of planets can toss these shredded bodies to the Earth. Hitting our atmosphere and heating, they first appear as streaks of light—meteors—crossing the sky. If large enough, they smack into us as meteorites to be visited in museums. The largest can dig giant craters in the ground, and in the most devastating of such events even wipe out whole species of life. Small rocks and dust grains flaked off comets produce a steady rain of such meteors, sometimes showers of them, sometimes whole storms of them to be admired. And comets can hit us too, with awesome force. Giant impacts on other planets can be so energetic as to launch rocks into orbit around the Sun, some of which eventually also hit us, giving us a cheap "space program," whereby we can take pieces of the Moon and Mars into our laboratories. Even stars can have such effects by gravitationally disturbing the outer icy cometary bodies, tossing them back toward us.

The Sun shines the same day after day. Inside is a highly controlled fusion machine that converts the solar hydrogen fuel into helium with the creation of energy. As the fuel runs out over long periods—billions of years—the Sun will gradually change. For a time, it will swell to swallow Mercury, perhaps Venus, perhaps in the ultimate solar effect even consuming Earth. It will then quietly shrink to a cooling dense ball comparable to our own planet's size. Other stars are not so lucky. Rare massive ones explode, whereupon they accelerate their surroundings outward at speeds close to that of light. The stuff rains down upon us as "cosmic rays" that manufacture the radioactive carbon that archaeologists use to date ancient ruins. Cosmic rays may even be the seeds that trigger lightning bolts, perhaps even some cloud formation, all from dying stars that are thousands of light-years away.

If near enough, the radiation from such explosions may be hazardous to life, indeed may even have caused one or more extinction events on Earth. Ordinary stellar explosions need stay at least 30 light-years away, while ultra-rare maximum detonations could damage us from thousands of light-years away. No wonder, since their effects can even be seen with the naked eye from *billions* of light-years' distance. The remains of these destroyed stars can be just as dangerous. Stellar blowups leave behind dense remnants that pack the mass of the Sun into balls no more than a few tens of kilometers across, into neutron stars that can have magnetic fields a million billion times stronger than Earth. Adjustments in these extreme stars and in their magnetic fields send out bursts of radiation so powerful that even though tens of thousands of light-years away, they can turn off orbiting satellites and disrupt communication.

In the ultimate connection, we came from out there. All the subatomic particles that make atoms and therefore ourselves were created in the Big Bang, the event that began our Universe. All the heavier chemical elements were made in aging and exploding stars, which also produced much of the energy needed to drive star and ultimately planet formation. We are not just *in* the cosmos, we are *of* the cosmos, we, along with all the other parts of it *are* the cosmos, all of it one, all of it allowing us to be born and to live our lives so as to understand and appreciate its grand beauty.