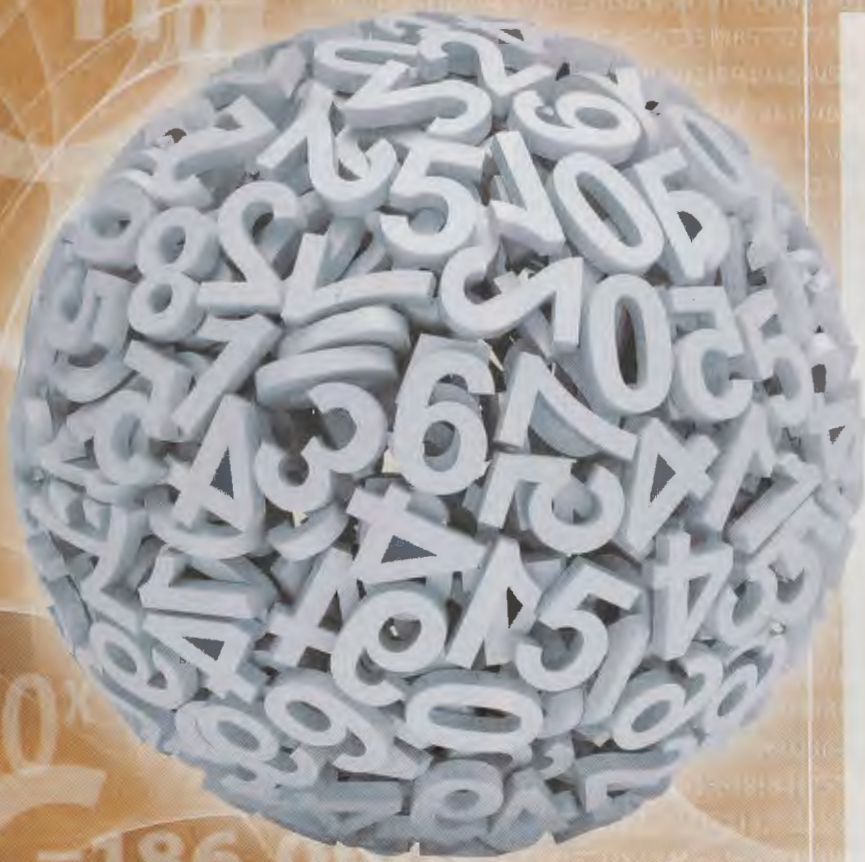


The 6 most important NUMBERS in the UNIVERSE

Find out how the speed of light, the gravitational constant, and other big numbers govern the cosmos. **by Bill Andrews**



Numbers are special. Every kid and sports fanatic has a favorite, something rarely true for letters or words. As humans, we seem consistently drawn to certain numbers, whether for some mystic mythological significance or their legitimate scientific importance.

While scientists don't put much stock in the healing power of 7 anymore, it's the odd physicist who doesn't have at least a healthy respect for the inviolate speed of light. From the makeup of the cosmos to the speed of its acceleration, here are a few of the universe's most significant numbers — at least, the ones we know so far.

Bill Andrews is an associate editor of *Astronomy*. He doesn't have a favorite number because he loves them all so much.

1 THE SPEED OF LIGHT

Hard as it may be to believe, the light we see all about us doesn't travel around instantaneously. The time it takes for the illumination of your lamp to reach your eye is infinitesimal, but measurable.

The first to quantitatively measure light's speed was a Danish astronomer named Ole Rømer, who analyzed how long it took a jovian moon's light to reach Earth over the course of our planet's orbit in 1675. Although his final figure was too low, his calculations helped prove the still-controversial idea that light had a speed.

Cosmic distances are so large that even speedy light takes its time getting somewhere, providing a handy way to measure astronomical distances: the light-year, or the distance light travels in a year (about 6 trillion miles [10 trillion kilometers]). Albert Einstein cemented the importance of this universal constant

when he proved that the speed of light in a vacuum, or c , is the maximum speed that matter or energy could ever achieve.

The symbol c originally stood for "constant" (though some suggest instead the Latin word for swiftness, *celeritas*). In fact, c is such a reliable value that since 1983 the International System of Units has defined the length of a meter as the distance light travels in $1/299,792,458$ second — the speed is *by definition* a constant.

However, it is possible for light to slow when it's not propagating through a vacuum, and sometimes space itself can expand faster than c . Certain quirks of quantum mechanics and other unexpected scientific discoveries

might end up showing that c isn't as immutable as we think, but for now, Einstein's designation of the universal speed limit remains the final word.



2 THE ORDER OF MAGNITUDE

At first, this might not seem like a worthy choice for our universal pantheon of numbers. How does the simple 10

compare to the speed of light or the gravitational constant? Easy: by being useful to scientists. Because of the way our number system works, 10 occupies a uniquely powerful position on the number line. (True, this is only the case in base 10, but it's the most common way modern humans count.)

Multiplying anything by 10 "adds a zero" to it, or gives it another order of magnitude. A house might be about 30 feet (9 meters) tall, but something an order of magnitude taller stretches up 300 feet (90m). An order of magnitude beyond that, and we're up to 3,000 feet (900m). The number 10 gives us a handy way to scale measurements up or down to suit our imaginations, whether in the realms of the unimaginably huge or the incredibly tiny.

This is perhaps best exemplified with the metric system of measurements. By establishing a single

standard unit of length — the meter — and using large multiples or small fractions of it to measure distances, an intuitive grasp of the relative sizes of objects becomes easier.

Earth's radius measures about 6,400 kilometers (or 6.4 million meters), and ultraviolet wavelengths of light peak about 10 nanometers (or 10 billionths of a meter) apart. Right away, scientists have a reasonable grasp on these extreme numbers, just by virtue of their being related by factors of 10. Even more importantly, it's easy to convert these measurements to the same unit (namely, meters) without the need for messy arithmetic.

Although not everyone appreciates or uses the metric system, as Americans well know, the order of magnitude is a valuable tool for a science that dabbles in the large and the small. The true power of 10 lies in its ability to link together all of astronomy's various phenomena.



3 THE GRAVITATIONAL CONSTANT

THE GRAVITATIONAL CONSTANT



- SYMBOL: G
- VALUE: $6.673 \times 10^{-11} \text{ N m}^2/\text{kg}^2$
- YEAR PROPOSED: 1687
- PROPOSED BY: Isaac Newton

NIST/C. Casey Beaud

Even the most casual student of physics will probably recognize G , the gravitational constant. All the various displays of gravity's effects, from planetary orbits around a star to stellar orbits around a black hole to galactic interactions over millions of years, would be impossible to determine without G . A fundamental constant of the universe, it defines how the masses of two objects and the distance between them are related to the gravitational attraction they feel toward each other.

Isaac Newton first theorized G in his law of universal gravitation (formally stated as $F=G(Mm/r^2)$), but the genius physicist never knew the actual value of G . It was British scientist Henry Cavendish who first measured it in 1798, 71 years after Newton's death. When it

came time for Albert Einstein to revolutionize the way physicists understand gravity, G was a common term in his equations.

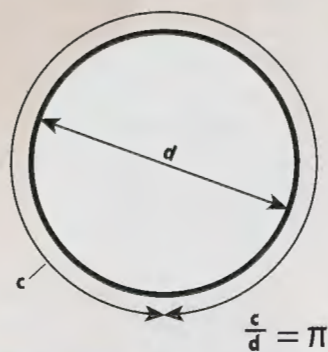
As important as G is to astronomers — they literally can't understand the universe without it — it's an unusually hard value to pin down. Its minuscule magnitude alone (written out long-hand, $G=0.00000000006673$) shows how weak the gravitational force is — far weaker than the other three fundamental forces.

Thus, it's been a difficult value to measure, and a study in the January 2007 issue of *Science* suggested a new value of $G=6.693 \times 10^{-11} \text{ N m}^2/\text{kg}^2$. Currently, the Committee on Data for Science and Technology and the National Institute of Standards and Technology recommend staying with the older value.

4 PI

For as long as people have understood mathematics, they've known pi. The ancient Greeks may have given us its common symbol, π (from their word for "perimeter"), but the Egyptians, Babylonians, Indians, and others knew of it.

One of the simplest and best-known universal constants, π represents the ratio of a circle's circumference to its diameter. This is true for any flat circle in the




Calculating π is as simple as dividing any circle's circumference (c) by its diameter (d), no matter its size. This simplicity belies the transcendental number's true complexity. *Astronomy: Kellie Jaeger*

universe, whether it's one the size of your hand or the size of the galaxy. The fact that it's an irrational and transcendental number, so its exact value is impossible to express handily (beyond the common approximation 3.14159), only adds to its allure.

In addition to its importance in geometry, π pops up in a number of important places. Werner Heisenberg's uncertainty principle — a pillar of quantum mechanics and thus our knowledge of the subatomic realm — features π . Albert Einstein's general theory of relativity equations also include the number, as do Johannes Kepler's laws of planetary motion and countless other scientific formulae. Our very understanding of the cosmos seems dependent upon π .

And the universe isn't the only fond of π . Whether it's as part of a nerdy school's sports cheer, an excuse to make and share pies every March 14, a device for testing the limits of memorization, a

PI



- SYMBOL: π
- VALUE: 3.14159...
- EARLIEST KNOWN USE: c. 1900 B.C.
- OLDEST CIVILIZATION KNOWN TO USE: Babylonian

Astronomy: Alison Mackey

way to prove God's existence, or a plot device in science fiction, the ancient constant enjoys a special place in the public's imagination. Any number that can combine everyday situations, the imagination, and the universe must truly be special.

5 DISTRIBUTION OF ENERGY DENSITY

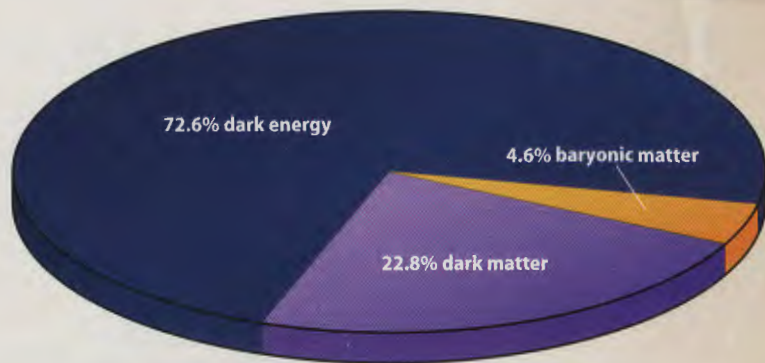
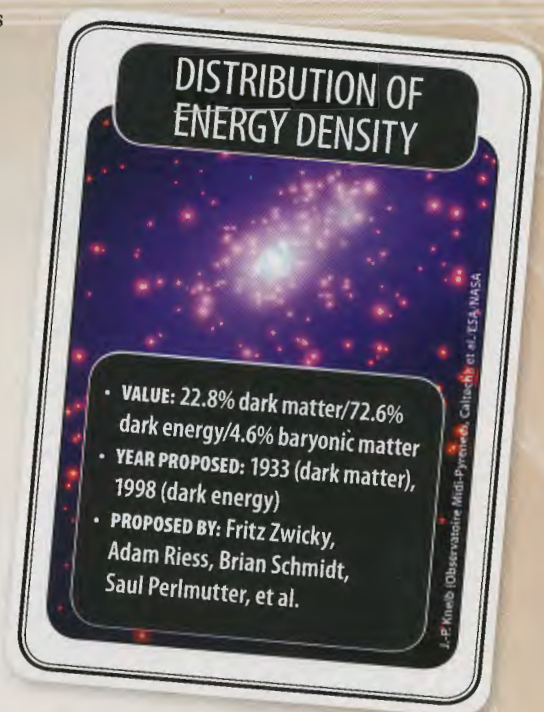
It's a disorienting fact that 95.4 percent of the universe's energy density (the stuff it's made of) is still a mystery to scientists. That remaining 4.6 percent, baryonic matter, encompasses everything on Earth, all the other planets, every star, every molecule of interstellar gas, and everything else scientists used to think made up the entirety of the universe. While we are now aware of the unknown 95.4 percent, about all we understand is that it's out there; just what it is and how it works are still up for debate.

The first part of that mysterious stuff is dark matter, and it makes up 22.8 percent of the energy density of the universe. When astronomers first started observing distant galaxies in the early 20th century, they noticed something funny: Galactic movement didn't make sense unless there was a lot of extra unaccounted-for mass out there. Quirky Swiss astrophysicist Fritz Zwicky suggested this could be the result of some unknown substance that had mass but was otherwise invisible and undetectable. It turns out that this odd "dark matter" positively litters the cosmos: It makes up 83 percent of all the matter we know of in the universe (and remember, all that matter is still only 27.4 percent of the total energy density of the universe).

The other mysterious substance out there is dark energy, first theorized in 1998 by American researchers Adam Riess, Brian Schmidt, and Saul Perlmutter trying to figure out how much the universe's expansion was slowing down. To

their great surprise, not only was all the mass of the cosmos not managing to pull back against the expansion, but something was actually speeding it up! Scientists dubbed this "something" dark energy, and apart from its tremendous prevalence in the universe — it's 72.6 percent of everything — scientists know almost nothing about it.

It might seem alarming to think that we're ignorant about the vast majority of stuff out there, but dark matter and dark energy also present a great opportunity: These are just problems awaiting solutions, and once science finds them, our understanding of the cosmos will be that much more complete.

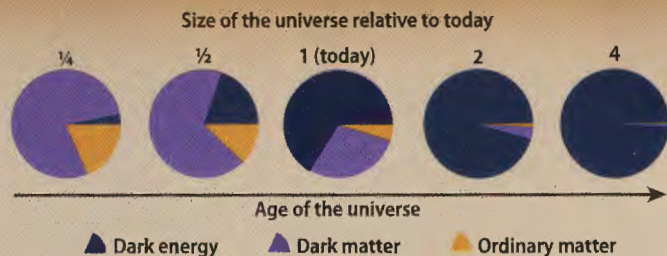


Remarkably, scientists understand only a tiny percentage of the known universe. The bulk of the universe's energy density — 72.6 percent — is dark energy, the mysterious force pushing our universe apart. Another 22.8 percent is still-unknown dark matter, leaving 4.6 percent for regular matter. *Astronomy: Kellie Jaeger*

THE COSMIC COINCIDENCE

We seem to live in a "special" time in the universe, when matter and dark energy experience a kind of equilibrium. Because regular matter dilutes as space expands, its density in the early universe was much higher than it is now. If dark energy is the cosmological constant, or a form of inherent energy of the universe, then its abundance stays constant. The ratios of these two quantities change dramatically over the history of the universe.

Why are they comparable now? Scientists aren't sure, but perhaps we live in one of many universes where everything — the laws of physics included — just happen to be perfectly tuned for our benefit. — B. A.



The distribution of energy density of the universe has likely changed dramatically over time. Dark matter had the clear majority when the universe was just one-fourth its present size, but as the universe expands, dark energy increasingly dominates. *Astronomy: Roen Kelly*

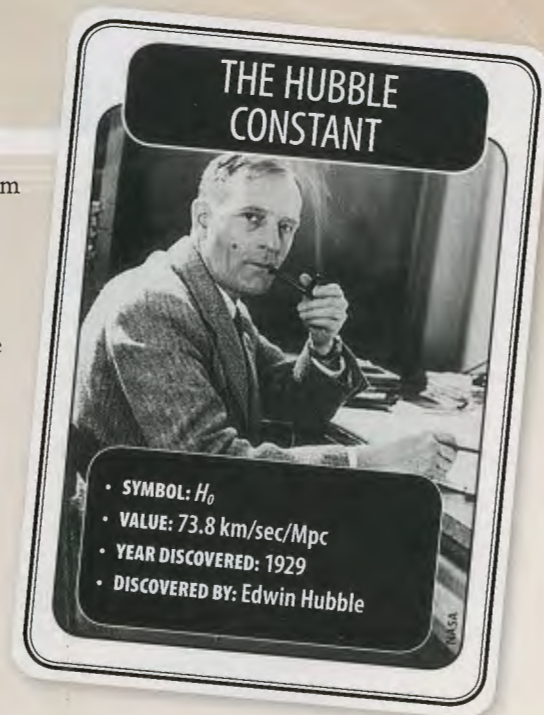
6 THE HUBBLE CONSTANT

We've all probably heard that the universe is expanding, stretching out ever farther since the Big Bang started it off. But much of our current notions of the cosmos arose thanks largely to one man: American astronomer Edwin Hubble. So, in addition to that famous space telescope, he also gets the Hubble constant named after him — the exact rate at which space itself grows.

The 1920s was a busy decade for astronomy and Hubble. Advances in telescope technology allowed him to make two groundbreaking discoveries. First, he realized that our galaxy, the Milky Way, is only one of countless star cities studded about the cosmos. Second,

he showed that these objects all seem to be moving away from us, and from each other, with the farthest galaxies moving fastest of all. Hubble hit upon the idea that a galaxy's velocity is equivalent to its distance times a certain constant, and it's this constant that became H_0 , the Hubble constant.

Its value is commonly expressed as 73.8 kilometers per second per megaparsec. This means, theoretically, that an object 1 megaparsec away (about 3.26 million light-years, or 30.8 quintillion km) moves away from us at about 73.8 kilometers



OTHER IMPORTANT NUMBERS

AGE OF THE UNIVERSE

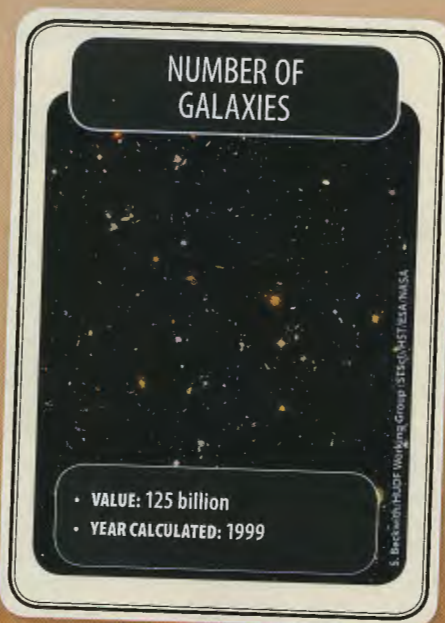
When Edwin Hubble realized the universe was expanding, it was a straightforward mathematical question to “turn back the clock” and imagine the cosmos shrink all the way back to the single event from which it sprang, known as the Big Bang.

NUMBER OF GALAXIES

The Hubble Space Telescope has given scientists an unprecedented view of the heavens and allowed them to estimate the number of star cities in the universe at a whopping 125 billion.

NUMBER OF KNOWN PLANETS

While the number of planets in our solar system is officially settled (if not to everyone's satisfaction), the number of exoplanets, those bodies orbiting stars other than the Sun, is constantly growing.



An expanding universe has long been an established fact in astronomy, but it wasn't until scientists learned the Hubble constant that they knew exactly how fast it grows.



Astronomy: Roen Kelly

per second. An object 2 megaparsecs away would have twice that speed, or about 147.6 km/s, and so on. (In real life, though, other factors are more important in determining the velocity of such nearby objects.)

Astronomers have been refining the Hubble constant's exact value for

decades, using various methods such as direct measurement of cosmic distances and analyzing the remains of the Big Bang, known as the cosmic microwave background radiation.

Knowing just how fast the universe grows is an important part of understanding the way it behaves. Armed with

an accurate value of H_0 , astronomers can answer more of the universe's fundamental questions, from the nature of dark energy to the locations of other members in our galactic neighborhood, and even the exact age of the universe. It turns out Edwin's namesake constant is almost as prolific as he was. ☪



Print out each of these trading cards featuring the universe's most significant numbers at www.Astronomy.com/toc.

SIZE OF THE MILKY WAY'S DISK

Astronomers had to work diligently to learn about our home galaxy because it's hard to get a good view from right in the midst of things; still, they've learned not just the diameter of the Milky Way's disk, but also its average thickness (some 1,000 light-years) and can even estimate its stellar population (about 200 billion).

DISTANCE TO THE NEAREST STAR

Proxima Centauri, likely part of the Alpha (α) Centauri system, would be an otherwise unremarkable dim red dwarf star were it not for its close proximity to Earth.

NUMBER OF KNOWN PLANETS HARBORING LIFE

Despite the myriad stars out there, each with a possible multitude of worlds, as far as scientists can tell, Earth is unique in the universe for giving rise to living beings ... for now.

