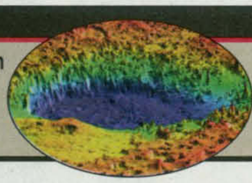

ASTRONOMY

Hubble Telescope Settles Cosmic Distance Debate—Or Does It?

If—as astronomer Allan Sandage once said—all of cosmology is the search for two numbers, then the search might now be half over. A group of astronomers announced this week that they have finally nailed down the so-called Hubble constant, the rate at which the universe is currently expanding. Combined with the other object of cosmologists' search, the universe's density of matter and energy, the Hubble constant gives the age of the universe.

The constant's exact value has been rising and falling for decades, depending on the observer and the method of observation. So in 1991, the Key Project of the Hubble Space Telescope (HST)—led by Wendy Freedman of the Carnegie Observatories in Pasadena, California, Robert Kennicutt of the University of Arizona, and Jeremy Mould of the Australian National University in Canberra—set out to survey cosmic distances with HST and find the value once and for all. Now they are ready to call it settled. At a press conference on 25 May, Freedman and her 26 colleagues announced their number: The universe is expanding, they say, at 70 kilometers per second for each megaparsec (3.26 million light-years) of distance.

Not everybody is ready to call the search over, however. For a simple number, the Hubble constant is extraordinarily hard to pin down, requiring ingenious schemes to measure the exact distances to other galaxies. Sandage, also at the Carnegie Observatories, has spent a distinguished career looking for the value and is holding out for a slightly slower expansion rate. "The bottom line," he says, "is that the problem with the Hubble constant is not solved." But Freedman notes that the difference between his value and hers is now about 10%. Given the measurement's historical difficulties, she says, "boy, that's progress."

Astronomers have been trying to measure the Hubble constant since 1929, when Edwin Hubble—the constant and the telescope are his namesakes—found the first evidence that the universe is expanding. By comparing crude estimates of galaxies' distances with their velocities—easily measured from the "redshift" of their light—he found that galaxies act like tracer particles in a flow, and those farthest from us are moving away the fastest. Hubble later estimated that the universe expands at 558 kilometers per second per megaparsec. Unfortunately, that would make it younger than Earth's rocks. In recent decades better distance estimates have led to more plausible results, usually between 100 and 50.

Cosmic benchmark. NGC 4603, more than 25 megaparsecs away, is the most distant galaxy in which the flashing distance beacons called Cepheids have been seen.

In 1994, the Key Project team published a preliminary measurement of 80. The number implied a universe that was younger than its stars, and headlines at the time declared a cosmological crisis. But another team, led by Sandage with Gustav Tammann of the University of Basel in Switzerland, measured the constant at 55, implying a comfortably old universe and no age crisis.

The Key Project team aimed to settle the differences by remeasuring the Hubble constant using various methods. Each method relies on objects with known true brightness, called standard candles; their apparent brightness as seen from Earth then indicates their distance. The standard candle with the smallest error is a precisely varying star called a Cepheid variable, which brightens and dims in periods that depend on its true brightness. HST can see Cepheid variables out to 25 megaparsecs—the distance of nearby galaxies. But at that distance, any measure of expansion is swamped by the gravitationally induced turmoil of our local cluster of galaxies. A believable Hubble constant has to be measured at distances closer to 100 megaparsecs, where the expansion is fast enough that local motions are mostly negligible.

Other standard candles do reach those distances. Spiral galaxies, for example, rotate at a measurable rate, which depends on their mass and presumably their true brightness. In elliptical galaxies, the internal motions of stars serve as the same kind of proxy for brightness. These and other not-too-standard candles, however, have measuring errors of 20%. A more precise standard candle is a kind of supernova called a Type Ia, which explodes with predictable brightness, is visible to about 500 megaparsecs, and has errors of just under 10%. All of these techniques give only relative distances, however. To get a Hubble constant, says Freedman, "you want distance in meters. Cepheids give you that."

The Key Project took 18 galaxies whose relative distances had previously been calculated with the other standard candles, then observed 800 Cepheids in the same 18 galaxies. They calibrated the other standard candles against the Cepheids. As expected, given the uncertainties in the methods, different standard candles gave different Hubble constants: Ia supernovae gave 68, the internal motions of elliptical galaxies gave 78, and "everything else," says Freedman, "is in between." Combining all the candles "gets the systematic errors to cancel out," she says, and gives an overall Hubble constant of 70. "The uncertainty is 8%—it's what we designed the Key Project to do."

Sandage isn't persuaded. "There's still a controversy," he says, "and this isn't going to settle it." The current dispute is over dis-

CREDIT: JEFFREY NEWMAN/UC BERKELEY AND NASA tances to the Ia supernovae, the best standard candles. For one thing, Ia's are rare: Only eight have occurred in galaxies close enough to have visible Cepheids. Since 1992, Sandage's team has used HST—although not as a part of the Key Project—to observe those Cepheids and has calibrated the eight Ia's accordingly. Their most recent Hubble constant from Ia's is 61.

Freedman's team combined the same Cepheid observations with new data and analyzed them with the method used by the Sandage team and another, independent method—a procedure, says Abhijit Saha of the National Optical Astronomy Observatories, who is on both teams, that "reflects differences in philosophy." As a result, Freedman says, her team found that "the Ia distances based on Cepheids are systematically closer by 8%," leading to a somewhat higher Hubble constant.

Whether the number is 70 or 61 or somewhere in between, it won't provoke another age crisis. Astronomers now believe that the universe's density of matter is low and its expansion is speeded up by an energy, called the cosmological constant, that pervades empty space. Both factors would push up the age of the universe with a Hubble constant of between 60 and 70 to around 13 billion years (see p. 1503). The oldest stars are between 11 and 14 billion years old. Because of uncertainty in the stars' ages, says Freedman, "there's still some tension, but there's no crisis."

So we can go on with our lives, right? Not yet. The Key Project's results "are 90% of the answer," says Robert Kirshner of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, "not the official end of the inquiry." Michael Turner of the University of Chicago agrees: "We're not quite done with this story. That last 10% is very important." Theorists' best model of the universe not only accommodates the mysterious energy of the cosmological constant, it actually requires it. "So we're on a roll," says Turner, who is himself a theorist. "But it could be snatched away by a more accurate measure of the Hubble constant." That's a matter of time: Satellites planned for the next decade should provide an accuracy of 1%.

If the final and exact value for the Hubble constant is well below 60, a cosmological constant could make the universe implausibly old, and theorists' favored cosmic model would be in trouble. "If a more precise value for the Hubble constant favors a universe with no cosmological constant," Turner says, "maybe we'll have another crisis—at least for the theorists."

—**ANN FINKBEINER**

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HUMAN GENOME PROJECT

Sequencers Endorse Plan for a Draft in 1 Year

COLD SPRING HARBOR, NEW YORK—Meeting in a closed session here last week, leaders of a dozen scientific teams endorsed an international plan to complete a "working draft" of the human genome by the spring of 2000 and polish it into a "highly accurate" version by 2003. The decision was a vote of confidence for Francis Collins, director of the U.S. National Human Genome Research Institute, and for Michael Morgan of Britain's Wellcome Trust charity. As chief funders of the nonprofit human genome project, they have been pushing for several months for such a scheme. They say they're doing this to satisfy researchers who want sequence data as soon as possible. But there's another objective: to stay ahead of a commercial rival—Celera Genomics of Rockville, Maryland—which announced in 1998 that it intends to sequence the entire human genome by 2001 and patent many genes (*Science*, 15 May 1998, p. 994).

Strategizing. Francis Collins (*left*) and Cold Spring Harbor Lab chief James Watson confer.

HUMAN CHROMOSOME ASSIGNMENTS REQUESTED BY MAJOR DNA SEQUENCING CENTERS

Baylor College of Medicine (R. Gibbs)	3, 12, X
MIT/Whitehead Center (E. Lander)	17, others*
Sanger Centre (J. Sulston)	1, 6, 9, 10, 13, 20, 22, X
U.S. Department of Energy (E. Branscomb)	5, 16, 19
Washington University (R. Waterston)	2, 3, 7, 11, 15, 18, Y
France (J. Weissenbach)	14
Germany (A. Rosenthal, H. Bloecker, H. Lehrach)	8, 21
Japan (Y. Sakaki, N. Shimizu)	8, 18, 21, 22

* Center director Eric Lander said MIT will sequence "whatever needs to be done."

When Collins and Morgan first floated the new plan in March, they embarked on a risky course: They essentially urged their own grantees to accept lower quality data—at least in the short term—to speed up production (*Science*, 19 March, p. 1822). Until then, the project aimed to produce a genome that is 99.99% complete, with most stretches of the genome sequenced 10 times over to reduce errors, by 2003. Now, they are asking grantees to produce a rough draft that will be at least 90% complete with fivefold redundancy. Some researchers were uneasy about this lowering of standards; had there been open dissent, the plan might have split the community.

That didn't happen, although some European members of the group were unhappy with the way the plan came about. They felt left out when Collins and Morgan switched gears in March. Andre Rosenthal of the Institute of Molecular Biotechnology in Jena, Germany, and Jean Weissenbach of Genoscope in Evry, France, made their objections known. The Anglo-U.S. leaders were "arrogant," Rosenthal says, to take this step without including everyone. And even U.S. scientists found the change tumultuous. It "made hamburger of all our plans," acknowledges Elbert Branscomb, director of the Department of Energy's Joint Genome