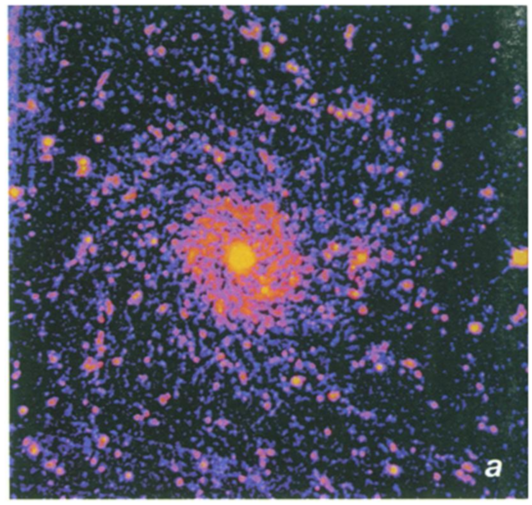
Searching for Cosmology's Holy Grail

Hubble telescope joins a constant battle



Pierce *et al.*/NATURE

By RON COWEN

Grown-ups love figures. When you tell them that you have made a new friend, they never ask you any questions about essential matters. They never say to you, "What does his voice sound like? What games does he love best? Does he collect butterflies?" Instead, they demand: "How old is he?"

— Antoine de Saint Exupéry, *The Little Prince* *

How old is the universe?

After years of fractious debate, astronomers still don't know the answer. Some believe the universe is 10 billion years old, others argue that it's closer to 20 billion. At the center of the controversy lies a number that has obsessed astronomers for decades — the Hubble constant.

The Hubble constant represents a measure of the rate at which the universe is expanding — how rapidly each object in the universe speeds away from any other object. Armed with this knowledge, scientists can estimate the age of the cosmos — how long since the Big Bang it has taken galaxies to reach their current locations.

The trouble is, no one can agree on the size of this constant. At best, astronomers have pinned the number down to within a factor of 2. Based on conflicting sets of observations and personal prejudices, two camps have sprung up since the 1970s. Several groups of researchers, using different measurement methods, favor a high value for the Hubble constant. This suggests a relatively small, young universe — one that began its expansion about 10 billion years ago. Others argue for a low Hubble constant, implying a cosmos about twice as big and twice as old.

Many researchers are hoping that the recent arrival of another Hubble — the Hubble Space Telescope — may resolve the controversy. Last December, the telescope got a new pair of eyeglasses and a new camera with built-in optics to correct for Hubble's notoriously flawed primary mirror. The corrective optics enable the telescope to produce sharp images of individual bright stars in galaxies 10 times farther from Earth than had been possible before. Three independent teams are now using the Earth-orbiting observatory to measure the Hubble constant. On Oct. 27, one of the groups will report some of the first results.

No one, including members of that research group, expects the findings to quell the controversy anytime soon. But over the next few years, observations with the repaired telescope may bring the war over the Hubble constant to an end.

"The Hubble Space Telescope is going to put the debate on a whole new level," says astrophysicist Robert P. Kirshner of Harvard University.

For a number that's the focus of so much controversy, the Hubble constant is conceptually simple.

In 1929, U.S. astronomer Edwin Hubble found compelling evidence that we live in an expanding universe. In particular, he made the remarkable discovery that when viewed from Earth, every distant galaxy appears to be moving away from our home galaxy, the Milky Way.

Hubble found that the more distant the galaxy, the faster it is receding. For example, consider two galaxies, one of which lies twice as far from the Milky Way as the other. The galaxy that resides twice as far away will appear to move away twice as fast. (According to general relativity theory, the galaxies themselves don't move; rather, the fabric of space in which they are embedded expands.)

The constant of proportionality between the distance of a galaxy and its speed is now known as H_0, the Hubble constant. In other words, the velocity of a galaxy is equal to H_0 multiplied by its distance from the observer. But H_0 provides the rate of expansion of the universe only for the present epoch. Because the mutual gravitational tug of galaxies slows the expansion that began with the Big Bang, this "constant" may have a smaller value now than in the past, when galaxies presumably parted company far more quickly.

By the same token, the inverse of the Hubble constant (1 divided by H_0), which gives the so-called Hubble age, provides only an upper limit for the actual age of the universe. Because the universe has a lower expansion rate now than in the past, the age of galaxies is less than it would seem from the present value of the Hubble constant.

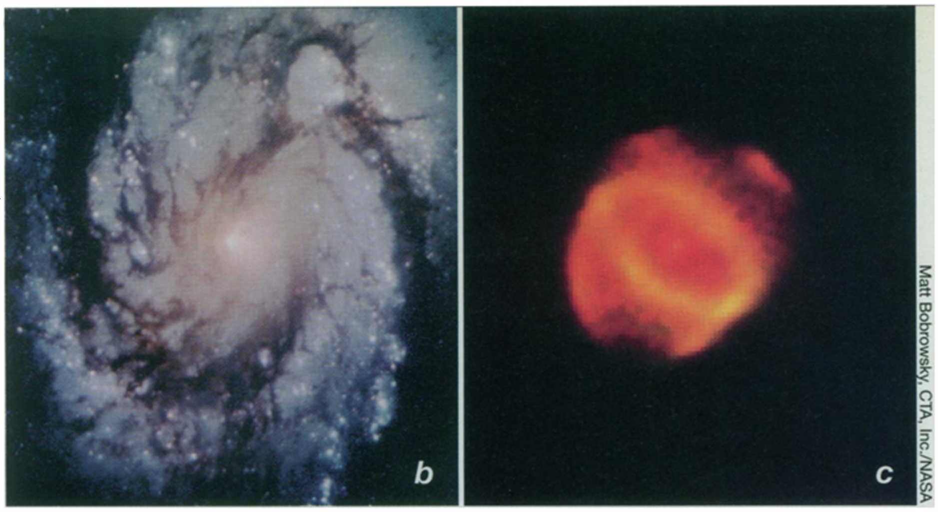
Scientists calculate H_0 by dividing the velocity of a galaxy, measured in kilometers per second, by its distance from Earth, typically measured in millions of light-years. Astronomers can easily obtain a velocity. They simply analyze the spectra of light emitted or absorbed by a galaxy. The spectra of an object moving away from Earth are shifted to redder, or longer, wavelengths; the greater the redshift, the faster the velocity.

In contrast, measuring distance presents a far trickier problem.

For starters, although the universe as a whole is expanding, the gravitational pull of galaxies near the Milky Way can rival or even overpower the expansion. For example, the Andromeda galaxy, the nearest spiral galaxy to our own, actually streams *toward* the Milky Way. This means that astronomers can obtain accurate distances only to galaxies that reside 600 million light-years or more from Earth. At lesser distances, the expansion rate is adulterated by the effects of gravity.

Second, astronomers have no completely reliable way of directly measuring the distances to remote galaxies. Instead, most resort to a variety of indirect means to size the cosmos. By calibrating the distance to nearby galaxies and working their way outward step by step to more distant ones, astronomers hope to piece together a yardstick for the universe.

Most strategies for measuring distance require some kind of "standard candle," the celestial equivalent of a lightbulb of known wattage. For instance, suppose scientists believe they know the true brightness of a particular type of star — the luminosity that would be detected if an



***B**y enabling astronomers to measure the distance to galaxies, several standard candles light the way to the Hubble constant. For the first time, researchers have detected one of these candles, stars called Cepheid variables, in a Virgo cluster galaxy using a ground-based telescope. In this false-color image (a) of the galaxy, NGC 4571, scientists subtracted the galaxy's smooth distribution of background light to reveal its stars, including the Cepheids. Another team recently used the repaired Hubble Space Telescope to detect Cepheids in the Virgo cluster galaxy M100 (b). Planetary nebulae, the expanding shells of glowing gas surrounding dying stars, are another standard candle. The unrepaired Hubble took this image (c) of a nearby nebula, Hen 1357.*

observer were standing next to it. Light from a faraway source grows dimmer in proportion to the square of the observer's distance from it. So the faintness of that kind of star in a distant galaxy indicates how far away the galaxy is.

Yellowish, pulsating stars known as Cepheid variables remain the favorite, and many say the most credible, standard candle for estimating the distance to relatively nearby galaxies. These youthful stars, several times the mass of the sun, brighten and dim periodically. Researchers discovered a century ago that the rapidity with which Cepheids change their brightness is directly linked to their true luminosity. The longer the period, the greater the luminosity.

Astronomers, however, need more than one type of standard candle. That's because no single class of star or galaxy has proved completely reliable. In addition, the intrinsic brightness of some of the candles lends itself to calculating the distance to nearby galaxies, while other, more luminous indicators help measure the distance to objects farther away.

Compared with other standard candles, such as supernovas, Cepheids are relatively dim. Thus, astronomers had only observed them in galaxies no more than about 25 million light-years from Earth. But scientists now report that they have seen Cepheids in the Virgo cluster of galaxies — roughly twice as far from Earth.

Wendy L. Freedman of the Carnegie Observatories in Pasadena, Calif., and her colleagues, including John P. Huchra of Harvard, recently announced that they had used the repaired Hubble Space Telescope to identify and study several dozen Cepheids in a spiral member of the Virgo cluster called M100. The report is one of the first postrepair studies to measure the Hubble constant. Over the next 3 years, the team will use Hubble to search for Cepheids in other members of the Virgo cluster as well as in certain spiral galaxies used as distance indicators.

Freedman and her coworkers didn't divulge any numbers for the Hubble constant when they presented their work at an August meeting of the International Astronomical Union in the Hague, Netherlands. Instead, they'll report their conclusions in the Oct. 27 NATURE. But scientists who attended the meeting told SCIENCE NEWS that the findings from Freedman's group seem to indicate a distance for the Virgo cluster — at least the part of the cluster in which M100 resides — of about 50 million light-years and a Hubble constant of about 80 kilometers per second per megaparsec. This would indicate that the universe is about 10 billion years old. (One megaparsec is 3.26 million light-years.)

Several researchers, including Freedman, caution that M100's exact place in the Virgo cluster remains uncertain. Astronomers don't know if it lies in the front, back, or near the center of this huge grouping of galaxies, not all of which are the same distance from Earth. Moreover, M100 is but one galaxy. Despite these limitations, obtaining a distance to the Virgo cluster represents a milestone in measuring the Hubble constant.

Even at some 50 million light-years away, members of this cluster are too close to our galaxy to indicate directly the expansion rate of the universe. However, astronomers have calculated the relative distance of clusters that lie much farther away, using the distance between Earth and Virgo as their unit of measure. And some of these galaxy groupings are remote enough that researchers, including Freedman and her colleagues, can begin to calculate the true Hubble expansion rate.

"The problem boils down to this — if you know the distance to Virgo, then you know the distance to any other cluster," says Michael J. Pierce of Indiana University in Bloomington. Or, as Michael Rowan-Robinson of Imperial College in London told a group of astronomers in Edinburgh last April, "Detecting Cepheids in Virgo would settle the distance-scale controversy."

In a related result, a team that includes Pierce and Sidney van den Bergh and Robert D. McClure of the Dominion Astrophysical Observatory in Victoria, British Columbia, reports in the Sept. 29 NATURE the first ground-based observations of Cepheid variables in a Virgo cluster galaxy. The team detected three Cepheids using the Canada-France-Hawaii Telescope on Hawaii's Mauna Kea. A "tip-tilt" mirror that corrects for the blurring caused by Earth's atmosphere enabled the researchers to pick out a few Cepheids in the spiral galaxy NGC 4571.

Like Freedman's group, Pierce and his coworkers have but a single Virgo galaxy, and its location is uncertain. But the U.S.-Canadian team argues that NGC 4571 resides close to the center of Virgo. The galaxy contains relatively little gas, and the team suggests that a wind of hot gas known to reside at Virgo's center has blown away the material. They report that NGC 4571 lies about 49 million light-years from Earth and that H_0 is 87. This would indicate that the universe is less than 11 billion years old.

Pierce points out that several different types of standard candles yield similarly high values for the Hubble constant. But there's one important exception — an unusually brilliant stellar beacon called a supernova Ia.

Allan R. Sandage of the Carnegie Observatories, considered Hubble's heir, worked with the famous astronomer and has studied the Hubble constant for some 40 years. He and his colleagues have their own set of observations using the Hubble Space Telescope. They look for Cepheids in galaxies known to contain a type Ia supernova. These exploded stars form another set of standard candles. However, although researchers believe that most Ia supernovas have about the same intrinsic brightness, no one knows the exact brightness.

Using one candle — the Cepheids — to calibrate the luminosity of another — the Ia supernovas — Sandage and his team are perfecting a standard candle thousands of times brighter than the pulsating stars. Astronomers can detect Ia supernovas in galaxies 10 to 100 times farther away than the Cepheids.

Two years ago, using the unrepaired Hubble, Sandage and his colleagues found a Hubble constant of about 50, a value consistent with his team's earlier, ground-based results (SN: 7/4/92, p.4). Last year, they used the unrepaired telescope to calibrate two Ia supernovas in the galaxy NGC 5253. The team again found a Hubble constant of about 50. This number implies that the universe is about 20 billion years old.

That would make many theorists happy, because such an age doesn't conflict with the estimated age of globular clusters — dense groupings of stars in the Milky Way and other galaxies that appear to be about 16 billion years old.

But the multitude of observers who find evidence of a higher Hubble constant and a younger universe eschew such arguments. Says Paul L. Schechter of the Massachusetts Institute of Technology, "From my point of view, we're in a joint enterprise here, and the [theorists] say, 'Go out and measure.' And so we go out and measure it, and they turn around and say, 'You know, we really don't like that. So what if all the observers are pretty much getting the same number now. We theorists wish it were something else.'

"In a relationship, you'd call that betrayal."

Some astronomers who question Sandage's results say that Ia supernovas may come in more than one wattage and thus cannot function as a single standard candle. If Sandage's team has used Ia supernovas that are intrinsically fainter than the researchers assumed, this would artificially lower the value of the Hubble constant. Sandage refutes such speculation, insisting that there's nothing "abnormal" about the supernovas he has chosen to study.

Next month, he plans to report the results of new observations with the repaired Hubble Space Telescope. His team used the repaired Hubble to image Cepheids in two galaxies on the outskirts of the Virgo cluster that also contain Ia supernovas. The data should enable his team to calibrate further the Ia standard candle, Sandage notes.

"We're very patient people, and by November we will have two more calibrators of supernovas that have been called prototypes of type Ia. If we again get [the same value], then we will have five supernovas calibrated, and the critics cannot say much."

Another group of astronomers, which includes Nial Tanvir of the University of Cambridge and Thomas Shanks of the University of Durham in England, uses the Hubble Space Telescope to find Cepheid variables in the Leo cluster of galaxies, some 31 million light-years from Earth. The Leo cluster contains both spiral and elliptical galaxies, but Cepheids reside only in spirals.

Once they get an accurate distance for Leo, they plan to use elliptical galaxies in the cluster as distance indicators for other ellipticals that lie farther away. If successful, this strategy will yield the first distance calibrator for such galaxies. So far, say Shanks and Tanvir, their team is still analyzing the data.

The quest for the Hubble constant isn't just a numbers game, Shanks says. An accurate measure of the expansion rate could shed light on several mysteries in the cosmos.

For example, he notes, a high value for the constant would seem to make the age of the universe half that of the oldest stars in it, unless Einstein's theory of general relativity was modified. On the other hand, a low value could make the universe much older than the oldest galaxies.

The numerical value of the constant, says Shanks, could indicate how much of the universe consists of dark matter — hidden, possibly exotic material that doesn't emit light yet exerts a gravitational tug. And it may provide a hint about whether the universe contains enough mass to eventually collapse in on itself or whether it will expand forever.

Astronomers' obsession with the age and size of the universe may soon yield a deeper understanding of how the cosmos evolved — a payoff that might please even the Little Prince. □