The Universe Shows Its Age

A cosmic embarrassment is fading. By some new measures, the oldest stars no longer appear to be older than the universe as a whole

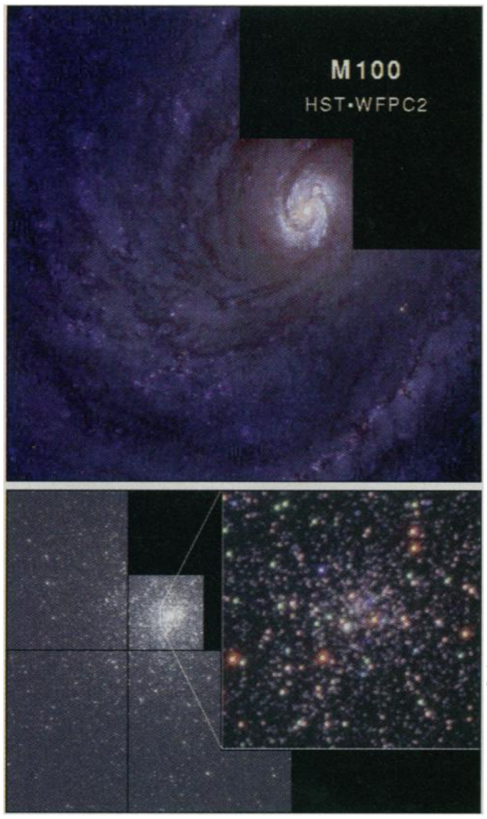
Four years ago, a nagging problem in cosmology looked set to erupt into a full-scale crisis. A team of astronomers led by Wendy Freedman of the Carnegie Observatories in Pasadena, California, published a long-awaited measurement of the universe's expansion rate, determined from Hubble Space Telescope (HST) observations of pulsating stars in a far-off cluster of galaxies. The result unnerved astronomers. The measured expansion rate was so fast that it implied that the universe has been slowing down for a mere 8 billion years since the big bang. Some earlier measurements of cosmic expansion had already pointed to worrisomely young ages for the universe, but this new result made it billions of years younger than its oldest stars appeared to be.

The crisis intensified the next year, when Craig Hogan of the University of Washington, Seattle, and Michael Bolte of the Lick Observatory in Santa Cruz, California, published a careful study of the nests of old stars called globular clusters, which reconfirmed earlier age estimates of about 16 billion years. The universe, it seemed, was just half the age of its oldest inhabitants. Something appeared to be drastically wrong with the observations, or with cosmologists' basic picture of the universe.

The discrepancy spurred a burst of activity on both sides of the age divide. Now, 3 years on, the crisis is abating. Improved theoretical models of stars and new, highly accurate data from the European Space Agency's Hipparcos star-mapping satellite have wiped billions of years off the ages of globular clusters, pushing them down to perhaps 12 billion years. And further Hubble observations, together with new techniques for measuring cosmic distances, have nudged the expansion age upward, with some figures now approaching 12 billion years as well.

"For the first time, what we are seeing are many different methods converging, and their error bars are overlapping," says Freedman. "Things have changed a lot in the last 6 months," says astrophysicist Brian Chaboyer of the Steward Observatory in Tucson, Arizona. What's more, a potential escape from the conflict has emerged: new indications that the overall mass density of the universe is much lower than many theorists had expected. If those results hold up, the age conflict could simply evaporate, because a lighter universe would be substantially older for a given expansion rate.

Although consensus is not a word in common use in the age debate, there is definitely talk of convergence. Chaboyer is bullish: "I now believe that the oldest stars are younger than the age of the universe, and that no crisis exists in cosmology regarding stellar ages." Others are optimistic but do not think the fight is over yet. "It is still true, as it was then, that some cosmological models predict an age [for the universe that] is too short," says Hogan. "The degree of the conflict for these models is not as bad as it was, but is still there."



Cosmic yardsticks. The Hubble Space Telescope picks out Cepheid variable stars in galaxy M100 *(top)* in the Virgo cluster to fix its distance, while pulsating RR Lyrae stars help give a fix on the globular cluster M15 *(bottom)*.

The trouble with Hubble

It is still too early to speak of a resolution, after all, when the various groups measuring the cosmic expansion rate still do not agree among themselves. The figure in dispute is known as the Hubble constant, which is the expansion rate measured in kilometers per second per megaparsec of distance (3.26 million light-years). To determine the Hubble constant, astronomers divide the speed at which the expansion is carrying a distant star away from Earth by the star's distance. The recession speed is easy to measure from the degree to which the distant object's light is redshifted—displaced toward the red end of the spectrum. The tough part is the distance.

Astronomers estimate distance by comparing the apparent brightness of the star with its true brightness. Judging a star's true brightness is tricky, too, but a set of unusual stars called Cepheid variables has seemed to offer an answer. Instabilities in the structure of these stars cause them to flicker in a regular way, and the period of the flickering is related to the star's true brightness. Knowing a Cepheid's apparent brightness, its flicker rate, and its redshift, astronomers in principle have all they need to measure the Hubble constant.

A further problem is that stars in our own galaxy or even nearby ones cannot give a true reading of the Hubble constant, because the gravitational pull of surrounding stars and galaxies generates motions that are hard to disentangle from cosmic expansion. "One of the primary motivations for building the [HST]," says Freedman, "was to allow the discovery of Cepheids out to a distance of the Virgo cluster," a cluster of galaxies about 50 million light-years from Earth. Her team's first analysis of these Cepheids yielded the 1994 paper, with its high Hubble constant of 80 ± 17.

Since then, Freedman's 27-strong team has continued to gather data, and they have moderated their claims slightly. "We have now measured distances to about a dozen galaxies," says Freedman. The team's current best estimate, based on their Cepheid measurements tied to more distant cosmological rulers, puts the Hubble constant at 73 ± 11.

That figure could still imply a disturbingly young universe, but other groups have marshaled HST data to argue that the universe is expanding much more slowly, which would make it older. Allan Sandage of the Carnegie Observatories and his collaborators at the Space Telescope Science Institute in Baltimore and at the University of Basel in Switzerland have combined Cepheids with another kind of beacon, the exploding white dwarf stars called type Ia supernovae. By observing

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—Wendy Freedman

Cepheids with the HST, Sandage and his collaborators were able to determine the distance to six galaxies, containing seven supernovae, including one in the Virgo cluster. From records of the supernovae's brightnesses as seen from Earth, the group could then determine their absolute brightness.

"The Hubble Space Telescope is required because type Ia supernovae are rare, and none is near enough that the Cepheids in the same galaxy could be observed from the ground," says Gustav Tammann of Basel. All seven supernovae had very close to the same maximum brightness, implying that this kind of supernova can serve as "standard candles"—objects whose distance can be inferred from their apparent brightness alone. Sandage's team went on to analyze about 30 other supernovae in galaxies far beyond the Virgo cluster, out of reach of the Cepheid yardstick. These supernovae gave an averaged value for the Hubble constant, published last year, of 58 +7/–8. "This is the most direct and most secure way to determine [the Hubble constant]," says Tammann.

The gulf between Freedman's result and Sandage and Tammann's may seem wide, but other methods are emerging that could break the impasse. For example, supernovae of a different cast, type II, can also serve as cosmic yardsticks. These explosions mark the death of giant stars when they collapse into neutron stars, hurling their outer layer of hydrogen and helium out into space in the process. They "glow like giant light bulbs," says Brian Schmidt of the Mount Stromlo and Siding Spring Observatories in Australia. Astronomers can measure the speed at which this envelope flies outward, and by cranking those observations into theoretical models, they can determine the absolute brightness of a type II explosion, and hence the all-important distance. Schmidt's recent best estimate of the Hubble constant with this "expanding photosphere" technique is 73 ± 7.

The optical illusions called gravitational lenses could also clinch a value for the Hubble constant. When light from a distant object passes near a massive galaxy or cluster of galaxies on its way to Earth, gravity can bend the light so that it follows several different paths. The result, as seen from Earth, is multiple images of the original object—and a celestial geometry that allows astronomers to infer the absolute distance of the object.

Tomislav Kundić of the California Institute of Technology in Pasadena, for example, has studied a lensing system in which a large elliptical galaxy in the center of a galaxy cluster creates a double image of a quasar beyond. "Because the light travel time is different along the two paths, variations in quasar brightness first appear in one of the images, and then, after a time delay, repeat in the second image," he says. This translates, via simple geometry and a model of the gravitational lens, into a Hubble constant of 64 ± 13, a result Kundić published last year. Emilio Falco of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, studied a different system to come up with a matching value, 62 ± 7.

Clusters getting younger

If all these techniques do converge—as some astronomers think they might—on a Hubble constant of between 60 and 70, the age problem would still be acute, unless the oldest stars give ground as well. And that is just what has happened in the last year. The sticking point had been globular clusters—containing what are, by common consent, some of the oldest stars associated with our galaxy. Roughly spherical groupings of about a million stars, they lie above and below the galactic disk.

To calculate the age of a cluster, astronomers mark the positions of all its stars on a chart of brightness versus temperature. All the stars in the cluster are roughly the same age but have a variety of masses. "Higher mass stars live fast and die young," says Chaboyer; hence, they take up positions in the hot, bright corner of the chart. Most of the rest of the stars form a diagonal line across the chart, from hot and bright stars to cool and dim. As the cluster ages, the large bright stars are the first to exhaust their primary nuclear fuel of hydrogen, and their surfaces begin to cool. Hence they begin to move away from the hot, bright corner, and the diagonal line develops a kink, called the turnoff point. Then slightly less massive stars also begin to run out of hydrogen and cool, and the kink moves down the line. The position of the kink on a brightness-temperature plot signals a cluster's age, but to determine it, astronomers need to know the stars' true brightness—and hence their distance. Therefore, Cepheids and other variable stars have again been their standard yardsticks.

Up until the mid-1990s, these kinds of studies had convinced most astronomers that globular clusters were between 16 billion and 18 billion years old, according to Francesca D'Antona of the Rome Astronomical Observatory. The situation was little improved by Hogan and Bolte's 1995 paper, putting them just short of 16 billion years, or by an almost identical result published the next year by Don Vandenberg of the University of Victoria in Canada. A few astronomers, including D'Antona and her colleagues, have recently begun holding out for younger ages based on a reappraisal of globular cluster theory. But their arguments would have remained on the fringe had it not been for the Hipparcos satellite.

Hipparcos mapped the positions of 120,000 stars 100 times more accurately than ever before, yielding data that were released to astronomers last June (*Science*, 21 February 1997, p. 1064). The Hipparcos results enabled Michael Feast of the University of Cape Town in South Africa and Robin Catchpole of the Royal Greenwich Observatory in Cambridge, U.K., to measure the distance to nearby Cepheid variable stars by parallax: tracking changes in the apparent position of a star relative to the background carpet of stars as Earth moves in its orbit around the sun. The farther off the star, the less it will appear to move. This distance measurement, which is independent of the brightness-flicker relationship, showed that the Cepheids in the Large Magellanic Cloud are about 10% farther away than was previously thought, according to Feast. In other words, Cepheids in general are brighter—

UNIVERSE AGES

Technique	Hubble constant	Age of universe (billions of years)	Group
Supernovae	58 +7/–8	12	Tammann
Gravitational lensing	64 ± 13 62 ± 7	10 11	Kundić Falco
HST Cepheids and Virgo cluster	73 ± 11	9	Freedman
Expanding photosphere	73 ± 7	9	Schmidt

STELLAR AGES

Stars	Age (billions of years)	Group
Globular clusters	11.5 ± 1.3 12.6 ± 1.5 12 ± 2	Chaboyer Peterson D'Antona
White dwarfs	9.6 8 ± 1.5	Oswalt Leggett

and hence farther away—than astronomers had realized.

The ripples from Hipparcos are now spreading through the age debate. The result pushes up the distances to globular clusters, which means their stars' intrinsic brightnesses must be greater, and shifts the brightness-temperature charts toward younger ages. "My current best estimate for the age of the oldest globular clusters is now 11.5 ± 1.3 billion years," says Chaboyer—a dramatic downward revision. The new Cepheid scale also affects measurements of the Hubble constant, says Feast. Of Freedman's value for the Hubble constant of 73, Feast says, "I would bring that down to 66 with my Cepheid scale." The revision does not blunt the conflict between Freedman's result and Sandage's, however, because Sandage's constant also comes down—to 54 or less.

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—Brian Chaboyer

Bruce Peterson, also at Mount Stromlo, and his colleagues on the MACHO Project have found that Hipparcos data support a revision in another distance scale, this one based on a different set of pulsating stars called RR Lyrae stars. They have been studying RR Lyrae stars in the Large Magellanic Cloud, relying on a quirk in pulsations of some of the stars that allows the team to tie down the actual star brightnesses very accurately. When compared with the observed brightnesses, this yields an accurate distance for the Large Magellanic Cloud that matches the new Cepheid distance. Applying the same calibration scheme to RR Lyraes in the globular cluster M15 "reduces the globular cluster ages by about 30%," says Peterson. His best estimate of the cluster age is 12.6 ± 1.5 billion years.

One dissenting voice comes from John Fernley, of Britain's University of Sussex, and colleagues, who used Hipparcos parallax measurements to check RR Lyrae distances and found that the traditional distance scale held up well. But the lower cluster ages are consistent with another set of stellar ages, from the ancient stars called white dwarfs, which Terry Oswalt of the Florida Institute of Technology in Melbourne describes as "basically the 'dead' cores of stars." Oswalt explains that white dwarfs "are slowly cooling. They shine only because they were initially very hot, and the cooling process takes billions of years."

Because of their faintness, astronomers can only see white dwarfs in our galactic neighborhood, but in that area they see none cooler than about 4000 kelvin. The implication of this abrupt cutoff is that even the oldest white dwarfs have not yet had time to chill out completely. Based on the cutoff and the estimated cooling rate, Oswalt and his colleagues will soon publish a best guess for the age of the galactic disk of 9.6 billion years. Add to that figure 2 billion years for the galaxy to collapse from the big bang and the disk to form, and "we get an absolute lower limit to the age of the entire universe of about 11 billion to 12 billion years," he says. A new white dwarf age result from Sandy Leggett of the Joint Astronomy Center in Hilo, Hawaii, and his colleagues, to appear in April's *Astrophysical Journal*, puts the age of the oldest dwarfs at a younger 8 ± 1.5 billion years.

Open-and-shut case

With this new batch of ages for the oldest stars, the battle lines in the age debate have shifted. If not for high Hubble constant readings like Freedman's, astronomers could be forgiven for heading to a betting shop and putting a sizable bet on 12 billion years as the age of the universe. But one surprise factor could make the entire debate moot. The young expansion ages are all based on the assumption that the universe is "flat"—that it contains just enough mass to prevent it from expanding forever. Many recent observations, however, indicate that the universe may actually be "open," its mass density low enough that it will expand forever rather than stopping or even collapsing again (*Science*, 4 April 1997, p. 37; 31 October 1997, p. 799; 21 November 1997, p. 1402).

The lower the mass of the universe, the less gravitational pull there is to slow its expansion: For an open universe, a given Hubble constant implies an older universe. A 12-billion-year open universe could easily have a Hubble constant as high as the one Freedman measured. "If it's as high as 73, it makes it look more like an open universe," says Feast. Whatever vintage the universe is, it now looks certain to last long enough for astronomers to figure out its true age.

–Andrew Watson

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INFECTIOUS DISEASES

A Method in Ebola's Madness

It's a demon suitable for a horror flick—a quick and gruesome killer. When the Ebola virus struck Zaire 3 years ago, it felled more than 160 people with symptoms that included raging fevers and widespread hemorrhaging—even from the eyes. From 50% to 90% of those infected in that outbreak and others died within 2 weeks, typically from shock. Now, researchers have a new clue about just what makes the Ebola virus so dangerous.

On page 1034, a team led by molecular virologist Gary Nabel of the University of Michigan Medical Center in Ann Arbor reports results suggesting that the virus uses different versions of the same glycoprotein—a protein with sugar groups attached—to wage a two-pronged attack on the body. One glycoprotein, secreted by the virus, seems to paralyze the inflammatory response that should fight it off, while the other, which stays bound to Ebola, homes in on the endothelial cells lining the blood vessels, helping the virus infect and damage them. "It's a remarkable paper," says immunologist Barry Bloom of Albert Einstein College of Medicine in New York City. It shows that these glycoproteins "can account for the two major aspects of the disease—failure of the immune response to kill the virus and damage to endothelial cells."

If confirmed in infected animals and humans, the findings suggest that these glycoproteins could be targets for anti-Ebola vaccines as well as for drugs that treat Ebola infections. And, in an ironic twist, some of this work could yield a new way to treat common ailments such as heart disease and cancer with gene therapies. The Ebola glycoprotein that homes in on endothelial cells could be attached to a harmless viral vehicle that delivers therapeutic genes to these cells, either spurring the growth of new blood vessels that bypass blocked coronary arteries or closing down the blood vessels that feed tumors.

Ever since Ebola was isolated 22 years ago, after the first outbreaks in Zaire and Sudan, virologists have sought the molecular weapons it uses to produce its deadly hemorrhagic fever. In 1979, Michael Kiley and his colleagues at what is now the Centers for Disease Control and Prevention (CDC) in Atlanta found a clue when they plucked from the viral surface a glycoprotein that looks like a molecular tool for gaining entry into animal cells. But the cellular targets of this molecule remained unknown.

To try to pin down this protein's role, the Michigan team, in collaboration with Anthony Sanchez at the CDC, induced cells to