Hubble War Moves to High Ground

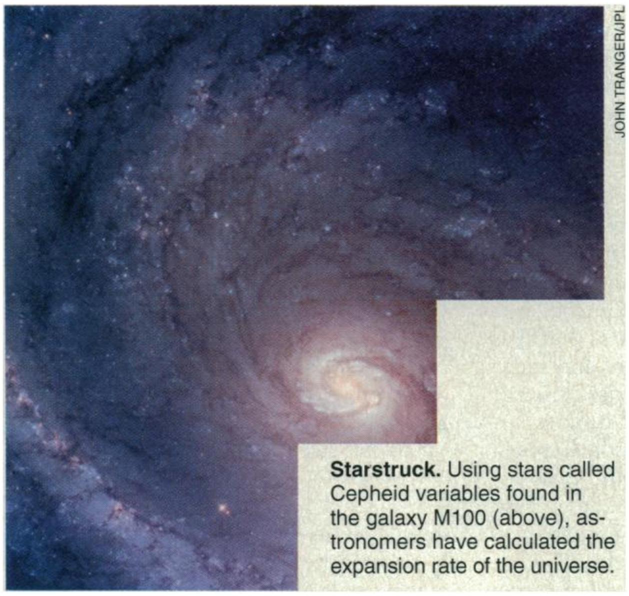
Three new measurements peg the celebrated Hubble constant at values high enough to give theorists nightmares. Is the debate finally over? Don't bet on it

In life, it has been suggested, there are just two unavoidable experiences: death and taxes. Cosmologists would probably add a third: arguments over the Hubble constant. This seemingly simple number provides a measure of how fast the universe is expanding. That value is fundamental to calculations of the distances to remote galaxies and other celestial objects, and it can also tell astronomers the age of the universe.

For all the apparent simplicity of this number, nothing about the Hubble constant is truly simple. Indeed, the search for its value has become the academic war to end all wars. One side's field marshal is Allan Sandage of the Carnegie Observatory in Pasadena, California, the acknowledged successor to Edwin Hubble. In the 1920s Hubble discovered that galaxies were rushing away from our own Milky Way and first calculated a value for the constant that bears his name. Over the years, Sandage and his soldiers have used a variety of methods to calculate the constant, the recent favorite being the brightness of exploding stars known as type Ia supernovae; they consistently report a value of around 50 kilometers per second per megaparsec.

But a much larger army of researchers, with its own approaches, champion higher values for the Hubble constant—somewhere in the 80s. And the latest salvos in this war suggest that the "high-Hubble" forces have made significant advances on the battlefield. In the last 2 months three independent groups have weighed in with high values for the constant. Furthermore, two of the groups base their results on the long-awaited detection of pulsating stars, known as Cepheid variables, in the group of distant galaxies known as the Virgo cluster. One team spied these stars with a ground-based telescope, a feat that was considered impossible until very recently; the other used the repaired Hubble Space Telescope (HST).

To cosmologists, these Cepheid results provide the strongest argument in years for a high Hubble constant, but most still refuse to accept the results unreservedly. Others are convinced that the verdict is finally in and that those still resisting a high value will not surrender only because of the consequences. "The argument that the Hubble constant is not 80 to 90 is based solely on its implications, not the data," argues Indiana University's Michael Pierce, who led the ground-based observations of Cepheids in Virgo. The implications of a high Hubble constant would indeed be profound. A high Hubble could create an age paradox in which the universe is several billions of years younger than some of the stars it contains. As that is obviously impossible, astronomers would have to radically revise their ideas about the evolution of the universe.



Starstruck. Using stars called Cepheid variables found in the galaxy M100 (above), astronomers have calculated the expansion rate of the universe.

Although this controversy is as current as the most recent issues of today's scientific journals, in principle little has changed in the way astronomers calculate the constant since Edwin Hubble made the first computation in 1929. The value for a specific galaxy is its recessional velocity, the speed at which the galaxy is traveling away from Earth, divided by the distance to the galaxy. The first number is relatively easy to obtain. Because the galaxy is speeding away from Earth, the light coming from it is stretched out by the Doppler effect, and its wavelength is shifted toward the red end of the spectrum. The amount of this "redshift" tells astronomers how fast the light source is moving. The distances to the galaxies, however, are harder to gauge, and it is these measurements that have split the Hubble constant researchers into two camps. Take the Virgo cluster: The high-Hubble constant battalion place it around 16 megaparsecs away; Sandage's army would almost double that figure.

The first shot exchanged between the two sides in the most recent skirmish comes from a relatively new method of determining distances that relies on observations of another type of supernova, called type II, which occurs when the core of a massive star collapses and explodes. Astrophysicists led by Robert Kirshner of the Harvard-Smithsonian Center for Astrophysics (CFA) in Cambridge, Massachusetts, have developed a method to turn these stellar blasts into reliable cosmic rulers. If one knows the actual size or brightness of a distant object, and also observes its much-reduced brightness or angular size as seen from Earth, simple geometry can then tell the observer how far away the object is. Kirshner and others believe that they understand the evolution of type II supernovae sufficiently to calculate the true sizes of these explosions by feeding observable data into theoretical models, and thus they can derive distances to them.

The beauty of type II supernovae, says Kirshner, is that they are so bright they can be viewed in galaxies at great distances, even well beyond Virgo. This is valuable because cosmologists believe the value of the Hubble constant can only be accurately measured by studying very distant galaxies. The reason is that the recessional velocities of nearby galaxies, even those in Virgo, are significantly distorted by the gravitational interactions of other surrounding galaxies.

When the type II–supernova method was first brought to bear on the Hubble constant question, Kirshner's data placed him squarely on the low-Hubble side. But as Kirshner and his team added more supernovae to their analysis and made subtle improvements to their models, their estimate of the constant has edged higher. And in the 1 September issue of the *Astrophysical Journal*, Kirshner and collaborators report on measurements of five more supernovae, putting their total at 18, and calculate a Hubble constant of 73 ± 13.

While the type II–supernova approach is a clear, simple strategy for finding the Hubble constant, the results obtained by using that method have not stirred up nearly as much attention as has the recent work on the Cepheid variables. That is largely because supernova models are still open to debate, while Cepheids are a well-tested standard for calculating distances, one Hubble himself used. "Nothing has the weight of the Cepheids. You get a number from them, and you want to believe it," comments George Jacoby of the National Optical Astronomy Observatory in Tucson, Arizona.

The calculation of distance to the Cepheids is based on their brightness, which varies in a regular fashion; the period of this variation has a strict relation to the star's intrinsic brightness. To obtain the distance to a Cepheid, astronomers simply measure its period, calculate its true brightness, and compare that to its brightness as seen from Earth. The problem with Cepheids is that they are dim bulbs, difficult to spot in the very distant galaxies needed for finding a value for the Hubble that is free of distortion. Astronomers have been frustrated for decades by their inability to push the Cepheid distance scale out to Virgo. "For a long, long time we have focused on the Virgo cluster," says Jacoby.

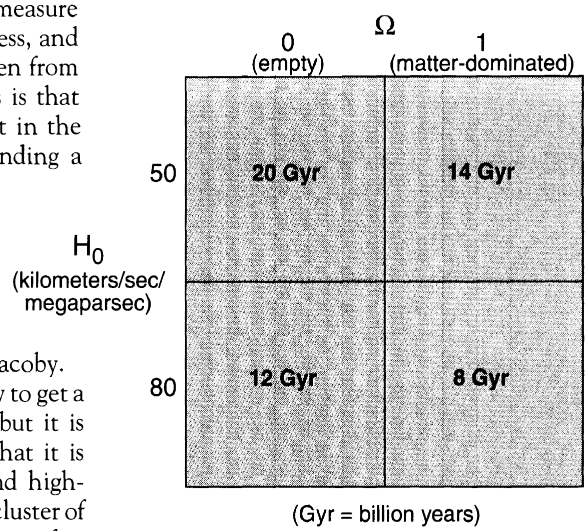
Virgo itself is not far enough away to get a good fix on the Hubble constant, but it is vital for two reasons. The first is that it is well-accepted by both the low- and high-Hubble factions that another dense cluster of galaxies, called Coma, is about 6 times farther away than Virgo's core, so a Cepheid distance to Virgo automatically gives astronomers a distance to Coma. And because Coma's velocity is thought to be relatively undistorted by gravitational fields of other clusters or galaxies, it should give the true value for the Hubble constant.

The second consideration is that the Virgo cluster is an excellent starting point for many distance indicators with a longer range than the Cepheids, such as planetary nebulae and the Tully-Fisher relation, which holds that the faster a galaxy rotates, the greater its intrinsic brightness. If they can obtain Cepheid distances to galaxies in Virgo, astronomers can calibrate these and other yardsticks and use them to measure the Hubble constant for much more distant galaxies with unprecedented accuracy.

These two factors made the Cepheids in Virgo the focus of great anticipation among astronomers. Because of the difficulty of spotting them, the HST was astronomers' big hope, but in 1990, when the infamous flaw was found in HST's primary mirror, those hopes were dashed. "It was a horrible development," says Pierce. So he and his colleagues began to look again at ground-based observation to see whether they could stretch the technology into spotting Virgo Cepheids.

It would seem that they have succeeded. In the 29 September issue of *Nature*, Pierce's group reports the discovery of three Cepheids in the Virgo spiral galaxy NGC4571. His group used the Canada-Hawaii-France Telescope atop Hawaii's Mauna Kea, which was fitted with adaptive optics, a recent breakthrough that rapidly shifts the shape of the telescope mirror to compensate for distortions caused by Earth's atmosphere. CFA's Kirshner calls the observations a "tour de force."

But while the field applauds the technical achievement, many also question the Pierce group's conclusions. For instance, some astronomers wonder whether the stars are truly Cepheids. "Have they really found variable stars? They're of dubious reality," says Barry Madore of the California Institute of Technology, a member of the HST team that has found its own Cepheids in another Virgo galaxy. Furthermore, questions have arisen as to whether the periods stated for each star are correct. Pierce freely admits that Cepheid data from the HST team will always be much better, but stands behind the work in his team's paper.



Age discrimination. An age of the universe can be calculated from the Hubble constant (H_0) and the amount of mass in the universe (Ω).

His group's three Cepheids give a distance to NGC4571 of around 14.9 megaparsecs. Then, by assuming that this galaxy sits directly in the core of Virgo, Pierce and colleagues used that number to derive a distance to Coma, yielding a Hubble constant of 87 ± 7. But, like the claim that they have really seen Cepheids, this calculation has drawn flak. Pierce's group argues that there is strong "circumstantial" evidence placing NGC4571 near Virgo's core, such as the fact that the galaxy has been "stripped" of hydrogen, a phenomenon thought to happen when a galaxy passes through a cluster's core. Others are more skeptical, however, noting that Virgo is a large, extended cluster and that the cores of clusters like Virgo are populated largely by elliptical galaxies, not spirals like NGC4571. At the very least, say detractors, the uncertainty over the galaxy's position relative to the Virgo core should be part of the error calculated for the Hubble constant. "Their error bars have been vastly underestimated in my opinion," says Wendy Freedman of the Carnegie Observatory, another member of the HST team looking for distant Cepheids.

Though criticisms swirl around aspects of the ground-based effort, its distance to Virgo has received some support from the very people that have been critical of it, namely those on the HST Extragalactic Distance Scale Key Project. This project finally got going after the National Aeronautics and Space Administration (NASA) repaired the HST in December 1993, and in this week's issue of *Nature*, Freedman, Madore, and the rest of the HST group report sifting through 40,000 stars to find 20 Cepheids in the Virgo spiral galaxy M100. From those Cepheids, the HST team has determined that M100's distance is 17.1 ± 1.8 megaparsecs, in the same ballpark as Pierce's estimate for NGC4571. "The HST data is far superior data [compared to the ground-based work]. People will prefer it," says Jacoby, one of the few outside the HST team to see the closely guarded data before publication this week.

From their M100 distance, the HST team estimate the Hubble constant to be 80 ± 17. But they do not claim that M100 is right in Virgo's core, which adds uncertainty to their estimated distance to Coma, and hence a large uncertainty to their Hubble estimate. Furthermore, they stress that the Key Project is a long-term effort whose goal is to accurately determine the Hubble constant by calibrating other distance indicators, not just Cepheid distances. Only when HST has observed Cepheids in other distant galaxies, in Virgo and elsewhere, will we "finally have the data to nail the Hubble constant for good," Freedman says.

That may be so, but, taken together, the three new measurements represent a formidable challenge to those favoring a low Hubble constant. Although a few new distance indicators pointing to a low value have popped up recently, they are not mature enough to carry much weight in the field, leaving Sandage's troops with the type Ia supernovae as their only weapon. "That's where the low–Hubble constant people are going to marshal their forces. I think it's going to be the type Ia where the final battles are fought," says Jacoby. Indeed, the skirmishes have already begun. Sandage and his colleagues have previously used HST-derived Cepheid distances to calibrate three supernovae in two galaxies and will soon report on two more supernovae, says the University of Oklahoma's David Branch, a supernova expert and Sandage collaborator. "The type Ia supernovae are not going away. I still think [the Hubble constant] is around

55," he says.

Branch may hew to the old line, but the high-Hubble movement has gained a lot of momentum. And, for most cosmologists, that's bad news. "There's a large part of the theoretical community that doesn't want to hear this answer," says Tully. The problem is that the Hubble constant is one of two numbers that cosmologists can use to compute the age of the universe. The other is the amount of matter in the universe, indicated by the Greek letter omega. An omega of 1 means there is enough mass to arrest the expansion of the universe—and this "flat" universe has strong theoretical support. But, according to standard cosmological theory, an omega of 1 and a Hubble constant of 80 equal a universe only 8 billion years old.

That would be fine, if it were not for the fact that stellar evolutionists have pegged the ages of some stars in globular star clusters at 13 billion years or older. Even an "impossible" omega of 0 (an empty universe) would not solve the problem; a Hubble constant of 80 then equals a 12-billion-year-old universe. Therefore, if the new, higher values for the Hubble constant turn out to be true, cosmologists will have their work cut out for them—adjusting their standard theory so that a realistic omega and a high Hubble constant yield a plausible age for the universe. It may not be as frightening as death or as infuriating as taxes, but after more than half a century the Hubble constant retains plenty of power to vex the astronomical community.

–John Travis

PALEONTOLOGY

Primate Origins: New Skull Fuels Debate

Today, the Fayum Depression, a gigantic bowl on the west side of the Nile River Valley south of Cairo, is a wind-carved, dusty place. But 36 million years ago, it was a tropical forest on the shores of the ancient Tethys Sea, teeming with the ancestors of monkeys, apes, and humans—and possibly lemurs and lorises. In this wind-swept basin paleontologists have been uncovering a trove of fossils that shed light on primate evolution. The latest treasure is a nearly complete skull from a never-before-seen type of primate. And, along with earlier finds from the same place, the new skull is fueling debate over whether the primate order is rooted in Africa, rather than in Asia as some primatologists have argued.

The new creature is described by Duke University primatologist Elwyn Simons and Washington University physical anthropologist D. Tab Rasmussen in the current issue of the *Proceedings of the National Academy of Science* (vol. 91, no. 21, p. 9946). It was a small, furry primate the size of a small cat, belonging to the suborder of prosimians. These "lower" primates are a group of arboreal, large-eyed, furry primates that today includes long-tailed lemurs and the smaller, nocturnal lorises and woolly bushbabies. The new find, says Rasmussen, was "a big-eyed, cute-looking prosimian with a large lower face. If it were to open its mouth, it would scare the hell out of you." The startle factor is produced by the creature's giant lower front tooth and a sharp daggerlike upper canine.

The 36-million-year-old skull is so different from anything found before that the researchers have placed it not just in a new species—*Plesiopithecus teras*—but in a whole new primate family and superfamily. Rasmussen and Simons decided *P. teras* couldn't be one of the "anthropoids," or "higher" primates that include apes, monkeys, and humans. That decision was made because the skull lacked certain anthropoid features such as an enclosed bony cup at the back of the eye.

The skull also had four premolars and a loop of bone behind its eye, features of primitive prosimians. But the skull's pronounced front tooth and wide lower face made clear it was a prosimian like no other. Says Philip Gingerich of the University of Michigan, who has seen the skull: "I think this animal is pretty odd." So odd, in fact, that it deserved its own family, Plesiopithecidae, and superfamily, Plesiopithecoidea, only the third superfamily of prosimians known from the Eocene, the period lasting from 55 million to 35 million years ago.

For this period, the new site where *P. teras* was found in the Fayum Depression—known as quarry L-41—has now produced a wider assortment of extinct primates than any other spot in the world. In the quarry, anthropologists have found at least three other primate families representing four genera of anthropoids and two of prosimians. "The whole world was warm and tropical ... and this site was bounding with little fuzzy lemurs and weird anthropoids," says Rasmussen.

RONALD L. USERY/DUKE UNIVERSITY

SENTURIA

Fossil find. Elwyn Simons *(above)* unearthed a new type of primate skull *(top)* in Egypt.

Indeed, Fayum L-41 is the only Eocene site with "undoubted anthropoids," says Rasmussen, because the purported anthropoids from other sites in Africa and Asia only include teeth, which are unreliable for distinguishing ancient anthropoids from prosimians. He and Simons contend that the presence of the anthropoids, as well as the overall primate diversity, suggest that anthropoids—and perhaps all primates—arose in Africa. These widely divergent primates, they argue, must have taken many millions of years to evolve from a common ancestor; in their view, that time frame pushes the common ancestor of anthropoids and prosimians in Africa back to about 45 million years ago.

But others doubt that the common ancestor existed in Africa. K. Christopher Beard of the Carnegie Museum of Natural History in Pittsburgh and his colleagues have found a wealth of new primate fossils in southeastern China dating back 45 million years. In a paper in the 14 April issue of *Nature*, they claimed that those fossils include anthropoids and prosimians (though with fewer genera and families than at the new Fayum site).

While some such as Gingerich think the purported Chinese anthropoid may be a hedgehog, it is clear there are several families of primates at the Chinese site—at an earlier date than in Africa. Asia has other old primate fossils as well, and the finder of two of them (45-million-year-old primates from Burma), University of Iowa paleoanthropologist Russell L. Ciochon, argues that "in many ways, the diversity argument is just as strong in Asia as in Africa."

The clincher, everyone agrees, would be to find an ancient primate on one continent or another that shows features ancestral to both the anthropoids and the prosimians. The latest find from Egypt isn't that. But as an odd, old prosimian, it is bound to make paleoanthropologists take a look at Africa as the possible cradle of the primates.

–Ann Gibbons