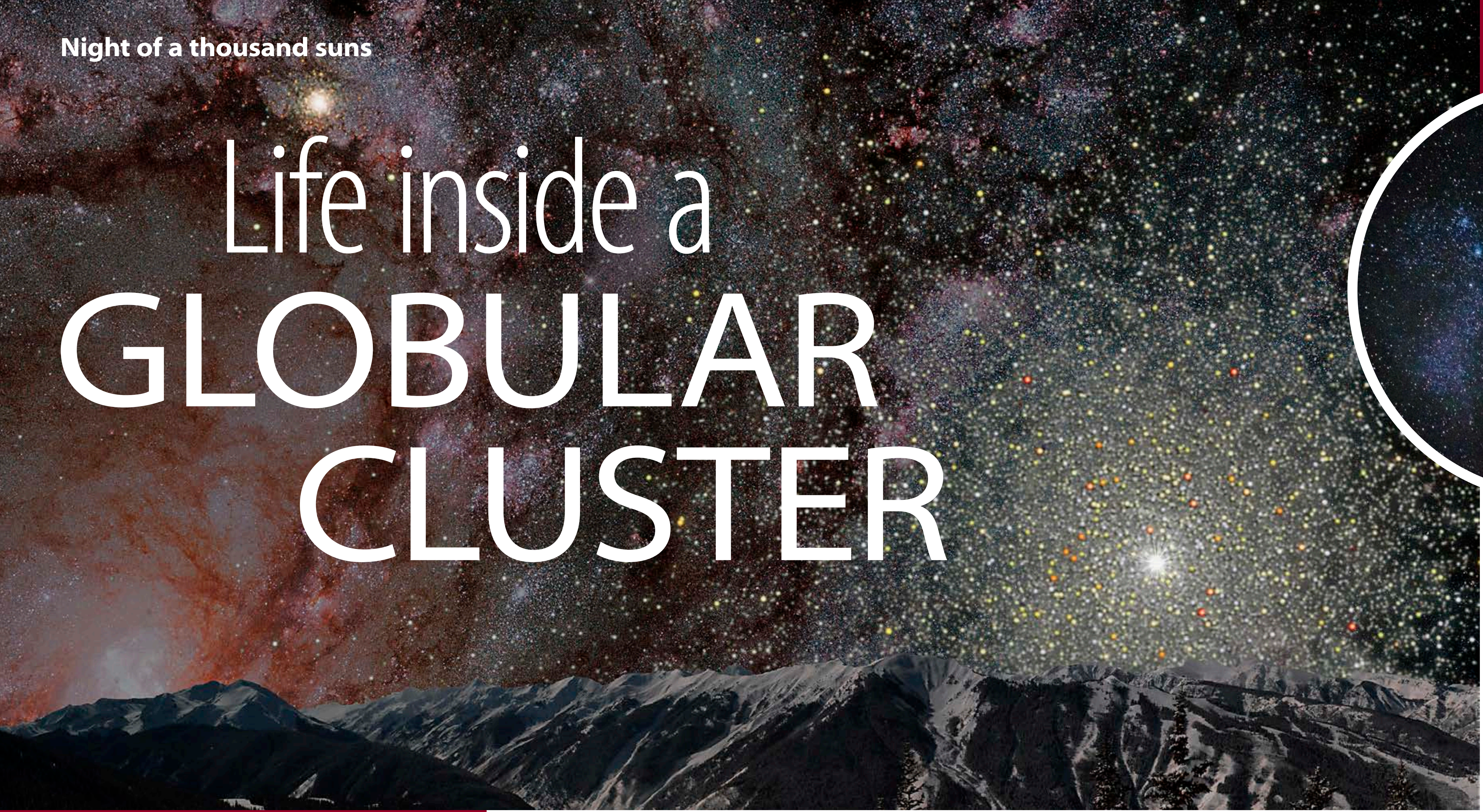

Night of a thousand suns

Life inside a GLOBULAR CLUSTER

33 LIGHT-YEARS FROM THE CORE

◄◄ The Milky Way's disk and the core of globular cluster 47 Tucanae vie for attention in the sky above a hypothetical planet located 33 light-years (10 parsecs) from the cluster's center. COMPUTER SIMULATION: WILLIAM HARRIS AND JEREMY WEBB (McMASTER UNIVERSITY); BACKGROUND GALAXY: NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

◄ Although just 2° of sky separate 47 Tucanae (lower right) from the Small Magellanic Cloud (left), a Milky Way satellite located some 200,000 light-years from Earth, the two are not gravitationally connected. G. BRAMMER/ESO

Imagine doing astronomy when 10 thousand 1st-magnitude stars light up your night sky. That would be the task facing scientists living in 47 Tucanae.

by William Harris and Jeremy Webb

What would the night sky look like from inside a globular cluster?

This question has inspired scientists, artists, and space enthusiasts for at least two centuries, ever since astronomers realized that these objects pack hundreds of thousands of stars into fairly small spheres. Perhaps no one explored the possibilities better than Isaac Asimov, who in 1941 wrote the short story "Nightfall" about just such a situation.

Asimov set his tale on the fictional planet Lagash, which, unbeknownst to the native population, lies in the middle of a dense star cluster. The plot throws in an extra twist by having Lagash orbit within a system that holds six stars. At least one of these suns is always "up," so perpetual daylight bathes the planet. Nobody alive has ever experienced night, let alone knows anything about what might exist beyond their own little planetary system.

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But once every 2,000 years or so, the orbits of five of the stars bring them around to the same direction in the sky, and the sixth one is eclipsed by a normally invisible moon. Lagash then finally experiences true night — and the rest of the universe suddenly becomes visible. None of the residents is prepared for the darkness; after all, who would bother to invent artificial lighting, for example, if it's always daytime? Asimov presents an arresting image of what deep night on Lagash would be like for its terrified inhabitants: "Not Earth's feeble thirty-six hundred Stars visible to the eye. … Thirty thousand mighty suns shone down in a soul-searing splendor that was more frighteningly cold in its awful indifference than the bitter wind that shivered across the cold, horribly bleak world."

But would the night sky inside a globular cluster really look like Asimov's vision of myriad stars spread across a pitch-dark sky?

Giants from the early universe

To answer this question, we created a hypothetical Earth-like planet that we could place anywhere inside a simulated but realistic globular cluster. About 160 such clusters scatter throughout our Milky Way Galaxy. These giant, deceptively simple-looking systems of stars spend their lives orbiting the galactic center, and most of them have done so for more than 12 billion years. They were among the first stellar systems to condense from the original supply of gas that emerged following the Big Bang.

While about half of the Milky Way's globular clusters orbit closer to the galaxy's center than our Sun does, the more distant ones have orbits that carry them well into the galaxy's vast spherical halo, even beyond 330,000 light-years (100,000 parsecs; 1 pc equals 3.26 light-years), where they can take a billion years to orbit the galaxy's core.

Every galaxy except for the tiniest dwarfs has its own retinue of globular clusters. The largest galaxies can hold an astonishing number of these behemoths. The supergiant elliptical galaxy M87 that lies at the center of the Virgo cluster, for example, has 13,000 of them. And even larger systems exist.

Not too hot, not too cold

To design our hypothetical Earth-like world, we wanted to make our creation as realistic as possible. Our first step was to abandon the intriguing but improbable idea that the planet could reside in a multiple-star system. Binary and larger systems are fairly rare within dense globular clusters. Worse, however, is the problem of finding a stable orbit for the planet. The task is already difficult in a two-star system, let alone one with three or more stars.

The two most common possibilities would have the planet orbiting either well outside the star system, in which case it likely would be too cold for life, or so close to one star (to prevent being pulled away by the companions) that it would be a roasting, Mercury-like world. To avoid these problems, we decided to place our Earth clone in orbit around a single star and at a distance where it would be in the "habitable zone" where surface liquid water and life can exist.

Second, we wanted the star itself to be a quiet, well-behaved one on the main sequence, the stage in its life when it generates energy by fusing hydrogen into helium in its core. And, like the Sun, it should have a comfortably long lifetime to allow intelligent life to evolve. Fortunately, these criteria aren't too restrictive because most stars in globular clusters are still on the main sequence.

Our third condition required the cluster to have a relatively high "metallicity," a term astronomers use to describe the amount of elements heavier than helium. Exoplanet studies show that the

AT THE CLUSTER'S CENTER

►► **From the core of 47 Tucanae, the sky is awash with bright stars. "Night" features some 10 thousand 1st-magnitude or brighter luminaries and more than 130,000 naked-eye suns.** COMPUTER SIMULATION: WILLIAM HARRIS AND JEREMY WEBB (McMASTER UNIVERSITY); BACKGROUND GALAXY: NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

► **Hundreds of thousands of stars pack into 47 Tucanae, making it one of the larger globular clusters in our galaxy. This ground-based view shows the entire cluster and starts to resolve some of its stars.** ESO/DSS2

probability of finding planets around a star goes up with its metallicity, and, in any case, a system needs these heavy elements to build rocky planets. Choosing a high-metallicity globular means that the cluster will spend most of its time orbiting pretty close to the galactic center because that's where astronomers find most such stellar conglomerations. Almost all of them lie closer to the core than the 27,200 light-years (8,340 pc) distance where our Sun resides. Thus, if we could see the broad swath of the Milky Way's disk across our model planet's night sky, it would look at least as big and bright as it does from Earth.

Finally, statistics will argue that more planets will be found in larger clusters with more stars. Putting all the conditions together meant we wanted to put our hypothetical planet around a single Sun-like star within a fairly big, high-metallicity globular cluster.

Into the jaws of 47 Tucanae

With these guidelines in mind, we developed a detailed computer simulation of a globular cluster. This model allowed us to place our planet at any point inside the cluster and then generate a realistic picture of the sky from that vantage point. Because the simulated cluster includes complete information about all of the model's stars, we can calculate how far away every individual star is from our imagined location, how bright it appears (its apparent magnitude), what its color would look like to the human eye, and how much total light our Earth-like planet would receive from the entire cluster.

The model cluster we built for this purpose contains 570,000 stars and has an average metallicity and structure similar to those of 47 Tucanae (NGC 104). This globular cluster, which lies deep in the southern sky in the constellation Tucana, is the prototype of a high-metallicity cluster in the Milky Way. Although 47 Tuc is not our galaxy's biggest globular cluster, it is fairly representative and fits most people's mental image of what such a cluster looks like.

We started with a mix of stars of different masses and then used standard stellar evolution models to evolve all of them up to a normal cluster age of 12 billion years. (We chose the initial mix of stars to yield the right relative numbers of main sequence stars, red giants, white dwarfs, and neutron stars observed after 12 billion years.)

A cluster like this will take roughly 100 million years to complete one orbit around the galaxy's center — comfortably long enough for life to evolve significantly and for the galaxy to stay in pretty much the same place in the sky from the viewpoint of stargazers on our imagined planet. In contrast, the stars inside the cluster will have typical elliptical orbits with periods of a million years around its own center. If we imagine a long-lived civilization with good record keeping, the people there would be able to report on the night sky's steadily changing appearance as their planet moves in toward the cluster's center and back out again.

Just for fun, we decided to run our visualizations with the cluster at its farthest distance from the galactic center (about 33,000 light-years, or 10,000 pc). And we chose an orbit that has carried the cluster up and well away from the galaxy's disk into the halo. As a stand-in for our galaxy in these images, we picked a recent Hubble Space Telescope mosaic of the nearby spiral galaxy M83, which is only slightly bigger than the Milky Way.

Diving into the cluster's core

Our first snapshot of the planet's sky (above) comes from a point in the cluster's core. All stars are color-coded by their surface temperatures. The luminous but rare red giants, stars that recently evolved off the main sequence, appear a deep orange; slightly less evolved subgiants and main sequence stars show a yellow or white hue.

At the center, our planet would be surrounded by a few hundred stars per cubic light-year (several thousand stars per cubic pc), which is thousands of times the stellar density of the Sun's neighborhood in the Milky Way's suburbs. The typical distance from our hypothetical planet to the closest star, however, still would be substantial — about 0.05 light-year (0.015 pc). In our solar system, this would place it beyond the inner edge of the Oort Cloud of comets.

Unless the closest stars happen to be red giants, none of them would have angular diameters large enough to resolve with the human eye, so all the stars still would appear as points of light. Across the entire sky, inhabitants of our hypothetical world would see 10,000 stars brighter than 1st magnitude — compared with just 29 in Earth's sky — and more than a thousand brighter than Earth's most brilliant nighttime star, Sirius. The brightest suns would blaze at apparent magnitudes brighter than –9, or 100 times more luminous than Venus appears from Earth. More than 130,000 stars would shine brighter than 6th magnitude, the naked-eye limit, compared with 6,000 from Earth.

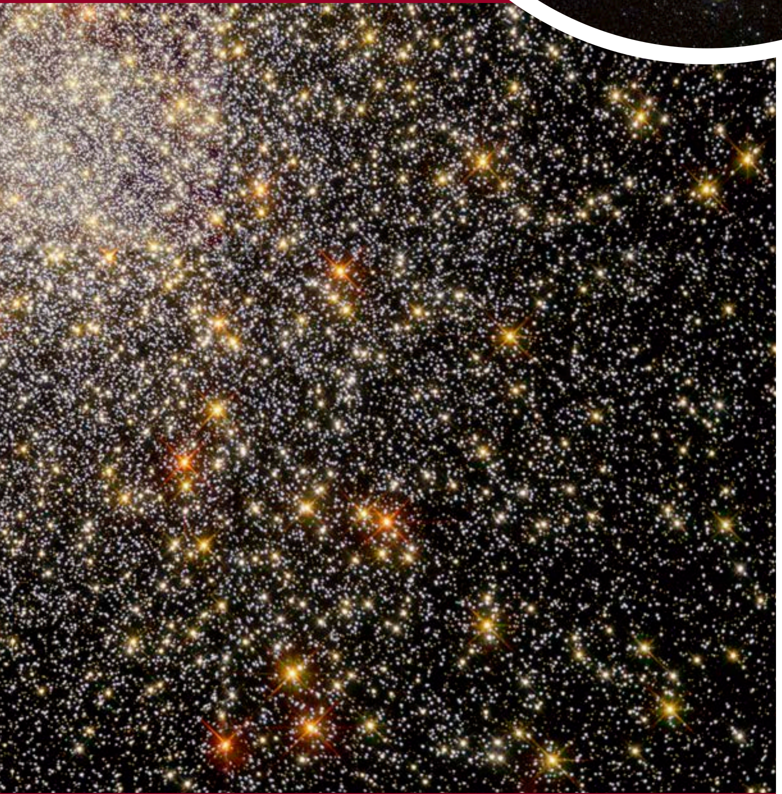
Although it might sound like lots of empty space still exists at the cluster's center, the prospects for doing astronomy from there would be discouraging. The biggest problem would be the sheer amount of light from all those stars. The cluster's suns would combine to give an average sky brightness some 20 times brighter than Earth's night sky at Full Moon (or about 16.7 magnitudes per square arcsecond). In other words, the darkest night our viewers would ever see would be a strange sort of twilight that possesses a kind of grainy texture unlike the uniform sheet of light we see on Earth. The galaxy's disk — already hard to see from Earth at Full Moon except from isolated locations — would be visible in the background but hard to study. Astronomers on our hypothetical planet likely would favor telescopes with small fields of view and excellent baffling against scattered light.

It might seem that stellar astrophysicists, at least, would have a field day from their perch because they could observe nearby stars at most evolutionary stages. But knowing the physical properties of stars first requires measuring their distances, and that wouldn't be easy. The gold-standard method is trigonometric parallax, in which observers measure the apparent shift of a star relative to a distant background of "fixed" stars as the planet orbits its sun. In the cluster

8.2 LIGHT-YEARS FROM THE CORE

►► From a vantage point 8.2 light-years (2.5 parsecs) from 47 Tucanae's center, half of the cluster's stars lie interior to our hypothetical planet's position. The cluster's central regions still dominate the sky while the Milky Way looms almost equally impressive. COMPUTER SIMULATION: WILLIAM HARRIS AND JEREMY WEBB (McMASTER UNIVERSITY); BACKGROUND GALAXY: NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

► Astronomers captured this image of 47 Tucanae through the Visible and Infrared Survey Telescope for Astronomy at Paranal Observatory in Chile. Because it includes some infrared wavelengths, the view highlights cooler, redder stars. ESO/M.-R. CIONI/VISTA MAGELLANIC CLOUD SURVEY



This Hubble Space Telescope view of 47 Tucanae reveals some 35,000 stars in the densely packed center of the cluster. The colors match what the human eye would see, with the reddish stars being mostly giants near the end of their lives and the yellowish ones more Sun-like objects. NASA/RON GILLILAND (STScI)

environment, few background stars would be visible because the cluster lies out in the galaxy's halo where field stars are few and far between. It would be difficult just to start measuring parallaxes.

Once scientists invent radio and X-ray telescopes, though, a lot of the outside universe would become detectable, but interpreting all those strange new signals would pose a challenge without the optically visible cosmos to compare them with. It would be vital for astronomers to make observations from orbit, where dark sight lines between the stars would exist and instruments could peer through them free of the blurring and diffusing effects of the atmosphere.

And here, deep in the cluster's core, other factors would make life dangerous. There would be a non-negligible possibility that a close encounter with a nearby star could disrupt the planet's orbit or even strip the world from its host star. The core of a large globular cluster also typically harbors dozens of millisecond pulsars or low-mass X-ray binaries — violent objects that would bathe the world in high-energy radiation if it ventured too close. And if the cluster happens to be one of the "lucky" ones that contains a central black hole, the planet's next trip through the core could be its last. All in all, the center of a big cluster doesn't seem like a good neighborhood to live in.

Welcome to the suburbs

Luckily, the planet and its parent star spend most of their time well outside the cluster's core. If we follow our planet as its star orbits farther out, we discover a wonderfully different picture. To illustrate this, we modeled what the night sky would look like with the planet 33 light-years (10 pc; see p. 18–19) and 8.2 light-years (2.5 pc; above) from the cluster's center. (The 8.2-light-year [2.5 pc] location lies at the "half-mass radius" that encloses precisely half of the cluster's mass and approximately half of its stars.) From either of these viewpoints, the world is still well inside the cluster. Stars remain gravitationally bound to the cluster out to a radius of about 165 light-years (50 pc). But once we move outside the cluster's core, far fewer nearby stars would hinder the view because the number of suns per unit volume drops roughly as the cube of the distance.

By far the brightest thing in the night sky would be the main body of the cluster, but the disk and central bulge of the Milky Way Galaxy would loom behind it all and stretch halfway across the sky. What kinds of fascinating mythologies would be built around this awesome view in early pre-literate cultures?

Although parallax measurements still would pose problems, doing astronomy from either of these vantage points would in some ways be better than from Earth. Observers would have a fine view of the entire galaxy and would not have to struggle, as earthbound astronomers have for decades, to disentangle the dimming and reddening effects of interstellar dust that mar the view from within the galactic disk. And by looking directly away from the center of the cluster, skygazers would have an uninterrupted panorama of the deep sky. This view would provide a perfect lead-in to studying galaxies and cosmology.

But an important shortcoming from these locations would be the difficulty in investigating the early stages of stellar evolution, starting with the interstellar clouds of gas and dust that give birth to stars and the subsequent life cycles of the most massive, short-lived stars. All these objects live in the galaxy's disk and spiral arms. Although they would be visible from farther out in the cluster, astronomers would have to study them from longer range. All in all, though, the night sky from these vantage points would be an exciting and wonderful thing to see. If we were free to choose, there's no doubt we would vote for one of these outer two spots.

In the end, the answer to our original question about what the night sky would look like from inside a globular cluster depends crucially on exactly where we imagine putting ourselves. In some ways, Asimov came pretty close to hitting the mark. ◑

TO WATCH A VIDEO THAT TAKES YOU FROM EARTH'S SURFACE INTO THE HEART OF 47 TUCANAE, VISIT **www.Astronomy.com/toc.**