How the universe has surprised us
Marcia Bartusiak; Stephen Lowe
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{ ASTROPHYSICAL SHOCKS }

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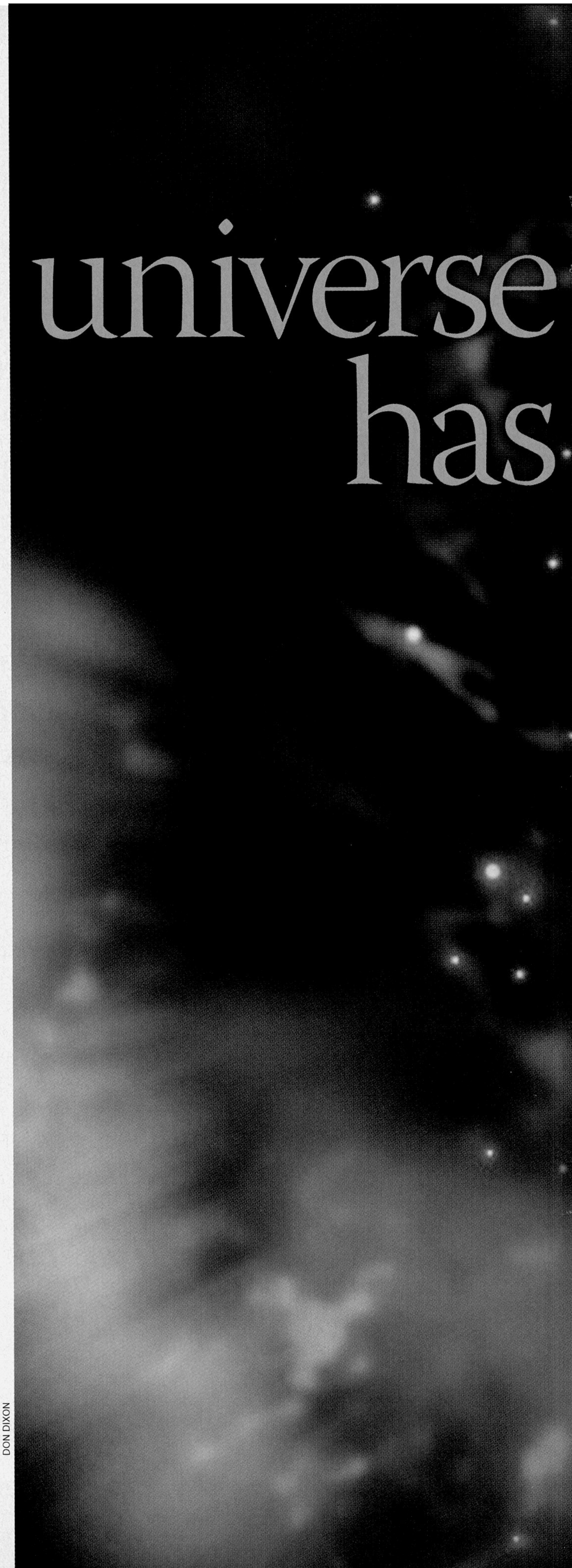


Astronomy's greatest hits come when the universe throws us a curveball. So what's coming next? **Marcia Bartusiak** and **Stephen Lowe** take a look into the future.

Everyone loves a surprise, be it an unexpected birthday celebration or the clever twist in a gripping mystery novel. Unlike these instances contrived by people, however, surprises in astronomy have a distinct beauty and thrill. Any new cosmic phenomenon, whatever it is, has never been experienced by any other person.

In 1572, on observing the sudden appearance of a bright star (now known to be a supernova), Danish astronomer Tycho Brahe quickly wrote a pamphlet grandly titled "On a New Star, Not Previously Seen Within the Memory of Any Age Since the Beginning of the World."

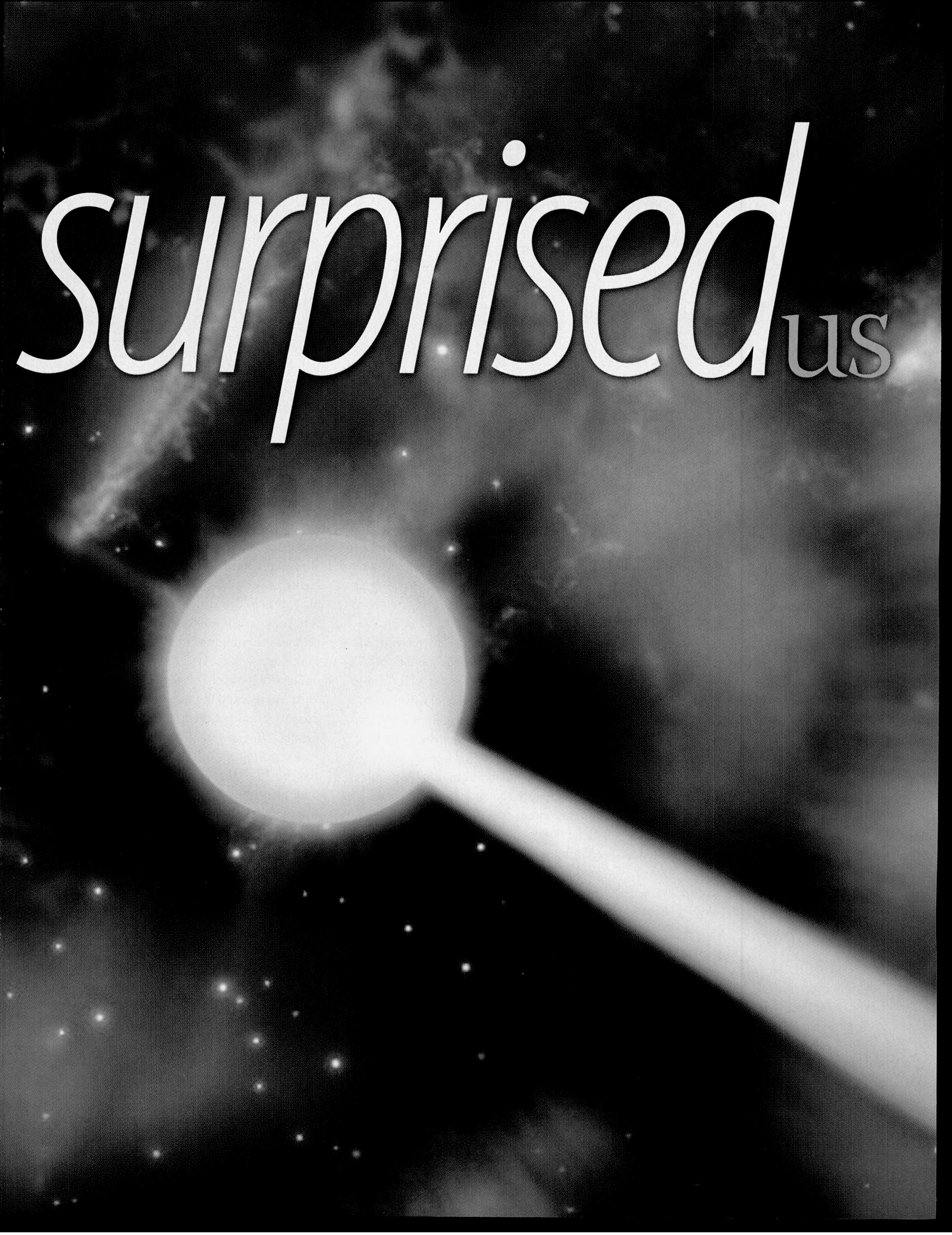
"I was so astonished at this sight," he wrote, "that I was not ashamed to doubt the trustworthiness of my own eyes." It challenged a notion, held since antiquity, that the starry heavens were unchanging.

Using an innovative spyglass in 1610, Galileo Galilei discovered the first moons circling another planet. He described the four moons of Jupiter as flying around the planet "at unequal intervals and periods with wonderful swiftness ... which [were] unknown by anyone until this day." As with Tycho's discovery, an astronomer had stumbled across something previously unknown.

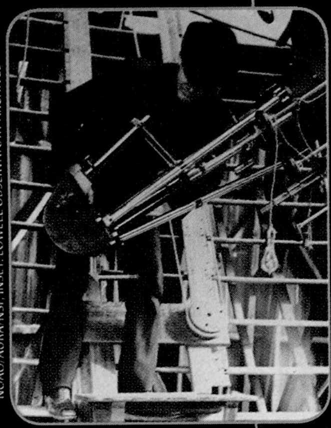
Nor has this trend abated over the centuries. While closely examining streams of radio telescope data in 1967, Jocelyn Bell (later Bell Burnell), a young British graduate student, uncovered the first observational evidence that neutron stars exist. Her suspect was emitting clocklike radio pulses. British astronomer James Hey noted that "no event in radio astronomy seemed more astonishing and more nearly approaching science fiction."

BEAMS OF RADIATION from the pulsar at the core of the Crab Nebula paint the expanding supernova remnant with energy. Long predicted by theory, neutron stars, soon dubbed pulsars, still surprised astronomers when they were found.

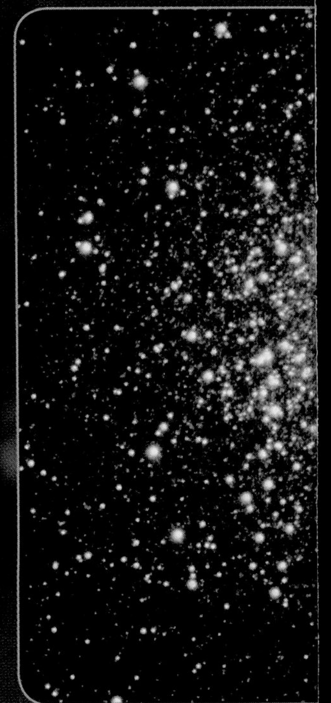
DON DIXON


surprised us

THE ANDROMEDA GALAXY jolted astronomer V. M. Slipher (below) with an unexpectedly high velocity. Spurred by the discovery, Slipher observed many more galaxies, finding the first signs of the expanding universe.



NOAO/AURA/NSF; INSET: LOWELL OBSERVATORY ARCHIVES



In some cases, a scientific discovery, while electrifying, just culminates a line of research spanning decades or centuries. Take Edwin Hubble's discovery of other galaxies, for example. Although breathtaking and historic, his finding was not surprising. Instead, it confirmed a viewpoint long suspected, settling astronomers' lengthy debate on whether spiral nebulae were indeed other "island universes" or mere appendages to the Milky Way.

But often a new fact walks up and hits astronomers in the face. Surprise occurs more frequently when astronomers try out a new instrument that enhances their vision, as with Galileo. And sometimes, it's simply the result of sheer persistence — the dogged searching through vast surveys of celestial denizens — that turns up a rare, odd bird that no one was looking for, as with Bell's neutron star.

Little green men?

Bell's discovery is probably the quintessential astronomical surprise. A neutron star is the core left when a massive star explodes as a supernova. A compressed ball of neutrons a dozen miles wide, the stellar remnant had been predicted, but nobody was looking for it. With no nuclear burning going on to provide power, it was assumed such a tiny star would be dark and all but undetectable. But astronomers didn't realize it could beep.

A platoon of students and technicians, led by Cambridge University astronomer Anthony Hewish, had just completed a sprawling radio telescope near campus. It was scanning the sky for quickly varying radio sources, such as quasars. Bell's job was to analyze the data scrawled on the chart-recorder paper — 400 feet a week.

Reviewing the output one day, she spotted a bit of "scruff," which on further examination was a repeated beep, a hundredth of a second long, occurring every 1.3 seconds. The astronomers briefly labeled it LGM for "little green men," a jesting nod to the possibility it was an extraterrestrial communication. Continued observations, however, soon uncovered more of these "pulsars." Within a year, Cornell University theorist Thomas Gold showed how a rapidly spinning neutron star could generate the signal.

Expanding the universe

The discovery of neutron stars was swift and sweet. But a surprise can also sneak up on astronomers, its real significance emerging only after years. Around 1910, Vesto M. Slipher at Lowell Observatory set out to obtain a spectrum of the Andromeda Nebula (M31) to determine its nature. At the time, no one knew if "spiral nebulae," cloudy patches resembling whirlpools, were nearby gas clouds — solar systems in the making — or far off aggregates of stars.

It was painstaking work, requiring dozens of hours at the telescope before the nebula's faint spectral features were captured.

Expecting to find Andromeda moving around 12 miles (20 kilometers) per second, like other stars in our galaxy, Slipher was astonished to find it rushing toward Earth at 200 miles (300 km) per second, or 0.1 percent the speed of light. This was the greatest velocity then measured for any celestial object, and it spurred Slipher to examine other nebulae.

By 1917, Slipher's list had expanded to some 25 nebulae, nearly all of them exhibiting tremendous speeds, up to 700 miles (1,100 km) per second. Moreover, most of them were moving away from us. However, astronomers had to wait more than a decade for an explanation. In 1929, Edwin Hubble and his assistant Milton Humason were at last able to confirm that the nebulae, by then known to be galaxies, are being carried outward due to the expansion of the cosmos.

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GLOBULAR CLUSTERS, such as M3, contains stars that are almost entirely hydrogen and helium, as first discovered by Cecilia Payne-Gaposchkin. Her finding came as a big surprise to astronomers in the 1920s.

WIYN/NOAO/NSF; INSET: HARVARD UNIVERSITY ARCHIVES

A BIT OF SCRUFF on a chart recording from a radio telescope told Jocelyn Bell Burnell she'd found something odd in the Crab Nebula. Not "little green men" but a pulsar, the first to be found.

NOAO/AURA/NSF; INSET: BIG EAR OBSERVATORY

Seventy years later, in 1999, the expanding universe begat a new surprise, when astronomers reported the cosmic expansion is not slowing down, as everyone confidently expected. Rather, the universe is accelerating due to the action of a yet-to-be-explained "dark energy" permeating space-time. Figuring out what this is could give us a profoundly new outlook on the cosmos.

Unusual abundances?

Then there's the surprise so startling no one wants to believe it at first. Beginning in the 1860s, astronomers were identifying elements in the Sun and stars that were assumed to be present in the same proportions as on Earth. If true, elements such as iron, silicon, and carbon would fill the universe.

But around 1925, Cecilia Payne (later Payne-Gaposchkin), then a graduate student at Harvard College Observatory, drew on new theories in physics to make the first calculation of stellar abundances. She found two elements were off the charts. Her equations were telling her that hydrogen is as much as a million times more plentiful in stars than on Earth. And helium is about a thousand times more abundant than the heavier elements.

Notified of Payne's unexpected finding, Princeton astronomer Henry Norris Russell informed her that it was "clearly impossible that hydrogen should be a million times more abundant." With atomic theory so new, he was worried the simplest element was exhibiting abnormal spectral behavior. Pressured by Russell, a noted authority, Payne diluted her claim. Although she published her results, she reported the abundances for hydrogen and helium were to be "regarded as spurious ... almost certainly not real."

FINDING ANTIMATTER in large amounts would be a surprise.

Yet just 4 years later, it was Russell himself who principally convinced astronomers of hydrogen's overwhelming presence in stars. After collecting more spectral data from the Sun, he was forced to conclude that the Sun's atmosphere consists mainly of hydrogen, "with hardly more than a smell of metallic vapors in it." Ironically, he made a point of reporting that there was a "very gratifying agreement" between his findings and Payne's original numbers — all the while failing to note his role in her labeling the data as "spurious."

Such surprises are part of astronomy's lore and permeate the science's epic history. There was William Herschel's recognition of Uranus, the first planet found since the dawn of history; the discovery of the Van Allen radiation belts around Earth; gamma-ray bursts popping off like cosmic flashbulbs; the universe's bubbly large-scale structure; and an unknown dark matter spread throughout space.

Earlier this year, astronomers were stunned to see fully formed clusters of galaxies in the farthest reaches of the universe that were created just a few billion years after the Big Bang. This is far earlier than anyone guessed was possible. It is "like a kingdom popping up overnight on Earth," said University of Michigan astronomer Christopher Mullis at the time.

How to expect a surprise

With such a track record, astronomers surely will have more surprises arriving in the future. When that will happen, of course, is hard to predict — if we knew it was coming, it wouldn't be a surprise. But history teaches us that certain arenas are fertile ground for unforeseen revelations. Among these, one of the most fruitful moments occurs when a novel instrument comes on line, especially one that opens up a new field of astronomy.

Many astronomers are betting that a surprise or two will turn up as they pursue one of the last predictions of Einstein's general relativity still unconfirmed: gravitational waves, or ripples in space-time.

To catch these, physicists have erected giant sensors in which laser beams race up and down miles-long pipes to detect the slight stretching and squeezing of space-time expected if a gravitational wave passes by. Each detector acts like a surveyor's stake in a worldwide network. By triangulating their measurements, scientists might be able to trace the gravity waves back to the stunningly violent events thought to generate these cosmic quakes — for example, a

SCIENTISTS ARE BETTING general relativity will turn up a surprise or two.

star burning out and exploding as a supernova, or two neutron stars or black holes smashing into one another.

Given that gravitational waves have been predicted, what might the surprises be? The most exciting possibility — the big, in-your-face surprise, the gravitational equivalent of Tycho's bright stellar flare — would be a clear signal revealing an unknown astronomical object or physical process.

Another surprise — a negative one — would be to discover that things astronomers already expect to be gravitational-wave emitters (stellar-mass collisions and detonations) don't play out exactly as we think they do. This would reveal flaws in our understanding.

Enough string

Syracuse University's Peter Saulson says another gravitational-wave source is cosmic strings, entities arising in some grand unified theories of physics. Flaws in the topology of space-time, cosmic strings can be thought of as extremely thin tubes, skinnier than an atomic particle, in which the energetic conditions of the Big Bang's primeval fireball still prevail. Such strings could be exceptionally long (spanning the width of the universe) or closed loops, and they continually vibrate at velocities approaching the speed of light, perhaps making them emit gravitational waves.

Even though such energetic objects would create sizable gravitational waves, the waves become extremely weak by the time they cross the universe to reach Earth.

The stretching and squeezing of space-time is expected to be smaller than the width of a proton. This forces gravitational-wave physicists to push their detectors to the limit, which may suppress immediate surprises.

One way to see the signal in the noise is to assume what the gravity-wave signal will be like. Just as knowledge of human speech patterns helps you make out words from a weak, far-off radio station, gravitational-wave physicists use mathematical models — templates — of gravity-wave signals. When analyzed, signals that match the models will be detected, but those that don't correspond will be written off as terrestrial or cosmic clatter.

Other gravitational-wave physicists hope to pick up weaker "unmodeled bursts" by carefully scanning for more generic signals such as persistent tones or smooth changes in pitch, or even combinations of these that occur together in a kind of brief musical score. Because astronomers don't presuppose the tune, this method may see truly unexpected gravitational-wave emissions that unveil new physics, new astronomical objects, or surprising information about known objects.

Search the familiar

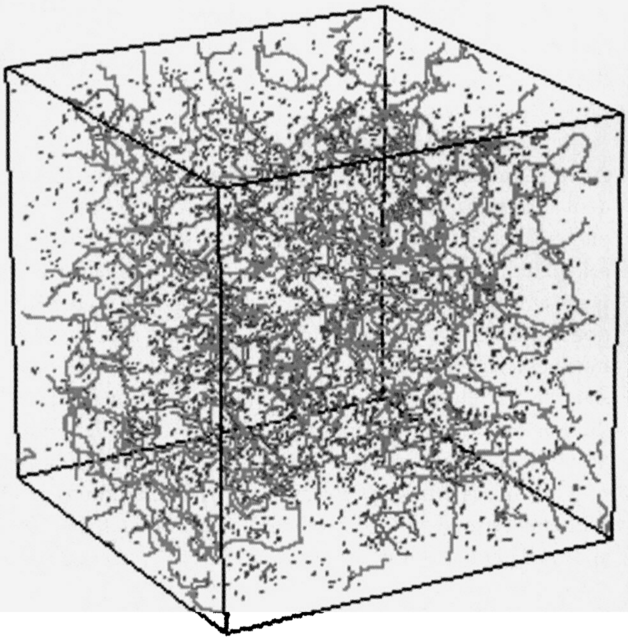
In addition to searching for novel objects, looking at collections of known objects might turn up some unexpected events. "In terms of the populations that create sources [of waves]," says MIT's Scott Hughes, "I think you have a little bit more room for a surprise." For example, gravity-wave observers expect to detect binary black holes spiraling in and merging, but what if they see a large number of such events?

"That would be an enormous surprise," says Hughes, "because I don't know where we would get them from." In other words, how could certain stars "arrange to die" so that many conveniently ended up as two black holes closely circling one another?

New capabilities in optical astronomy may lead to surprising discoveries in the search for extrasolar planets. So far, astronomers have depended on planets either being very massive or rapidly moving to pick them out. Consequently, only certain kinds of extrasolar planetary systems are revealed. None of the systems found so far closely resemble our solar system, with its rocky terrestrial planets close to the Sun and gas giants farther out.

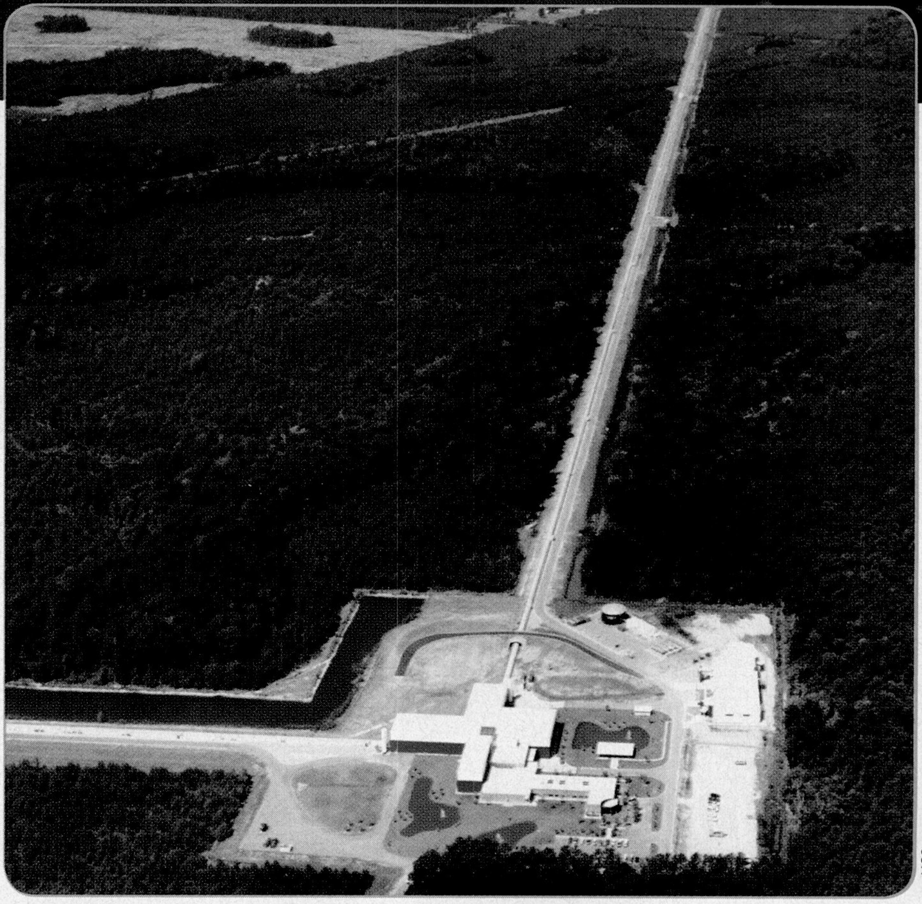
But planet-hunters are starting to look for transits — the passage of a planet between its star and the viewer — to detect a wider range of planetary sizes. By measuring the tiny decrease in light from the star due to the planet's shadow, as well as measuring the time required for the crossing, astronomers can extract information about the planet's size and orbit.

Of course, the alignment has to be just right (we have to be in the plane of the planet's orbit) and that means looking at lots of stars to find those lucky setups.



NATIONAL TAIWAN UNIVERSITY, J. H. P. WU

QUIVERING NANOTUBES comprise string theory's universe in place of particles. If correct, the theory may kick astronomy into new paths.



A SHIMMY IN SPACE-TIME will tell astronomers a wave of gravitational radiation has passed by, perhaps from two merging black holes (above). Racing laser beams look for gravity waves at LIGO, the Laser Interferometer Gravitational Wave Observatory (right).

But a NASA mission called Kepler, to be launched in 2007, will monitor 100,000 stars continuously and detect the transits of planets as small as Earth. This will be the perfect opportunity to find a planetary family looking like our own.

And once we can detect such planets, will we find that our solar system is the normal arrangement for planetary systems within the Milky Way after all? That's not clear. The first planetary systems sighted in the 1990s were found to be strange: planets more massive than Jupiter circling close to their suns.

Andrea Ghez of UCLA points out that at the time, astronomers' models for the formation of stellar systems "couldn't produce any of these weird-looking planets." The models had to be revised after the discovery.

"There's a whole cottage industry now of trying to explain how you get massive planets really close to the central star," she says. Because the models are still being adjusted, Ghez adds, "I just suspect that we're in for a few more surprises once we get down to being able to detect all the kinds of planets that are within our solar system."

Seeing new colors

Help in sorting out such riddles of stellar systems may come from submillimeter radio astronomy. Submillimeter is a part of the electromagnetic spectrum that is not well-covered, says John Huchra of the Harvard-Smithsonian Center for Astrophysics. "We're just beginning to get telescopes that work reasonably well," he says. "But, unfortunately, they have to be up at 18,000 feet [5,400 meters] in high and dry conditions. My suspicion is that we're going to learn a lot of things about star formation and protoplanetary disks, because submillimeter is a region that's pretty good for tracking that kind of activity."

Turning to our own celestial backyard, exploring Mars and Saturn's moon Titan have the potential to end the most suspenseful wait of all. "A profound discovery would be life," says Woody Sullivan of the University of Washington. "The surprise would be if it were completely different, either in chemistry or in its method of storing genetic information; or if it were not based on water." And there's always the hope the search for extraterrestrial intelligence will turn up some neighbors.

Phenomena whose causes are poorly understood are also good targets for unexpected findings. Consider the supermassive black holes lurking in the hearts of most galaxies. When first discovered, these central black holes were thought to be associated only with quasars and other active galactic nuclei, which spew out huge amounts of energy. "So the discovery that most galaxies have central black holes was a surprise," says Ghez. Then, it was a surprise to find that the size of the supermassive black hole correlated directly with the size of a spiral galaxy's central bulge. "Presumably," says Ghez, "that's one huge hint as to how galaxies form."

Astronomers are often reluctant to make predictions too off-the-beam, but John Huchra is willing to go out on a limb. He notes that, although we know antimatter exists, we've never detected a large piece of it, such as an entire antimatter star or galaxy. There's reason to believe these are not so common: to avoid emitting copious radiation from matter-antimatter annihilation, such entities would have to be isolated, even from the dusty, gaseous interstellar medium.

But an antimatter star far out in the galactic halo might be isolated enough. "So, one surprise would be the detection of a significant antimatter object," says Huchra.

It's easy for astronomers and astrophysicists to imagine all sorts of weird things, but ultimately, only a small fraction will turn out to exist. And things they don't imagine at all will make a sudden appearance out of the blue. Surprises like that just come with the territory. ■

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