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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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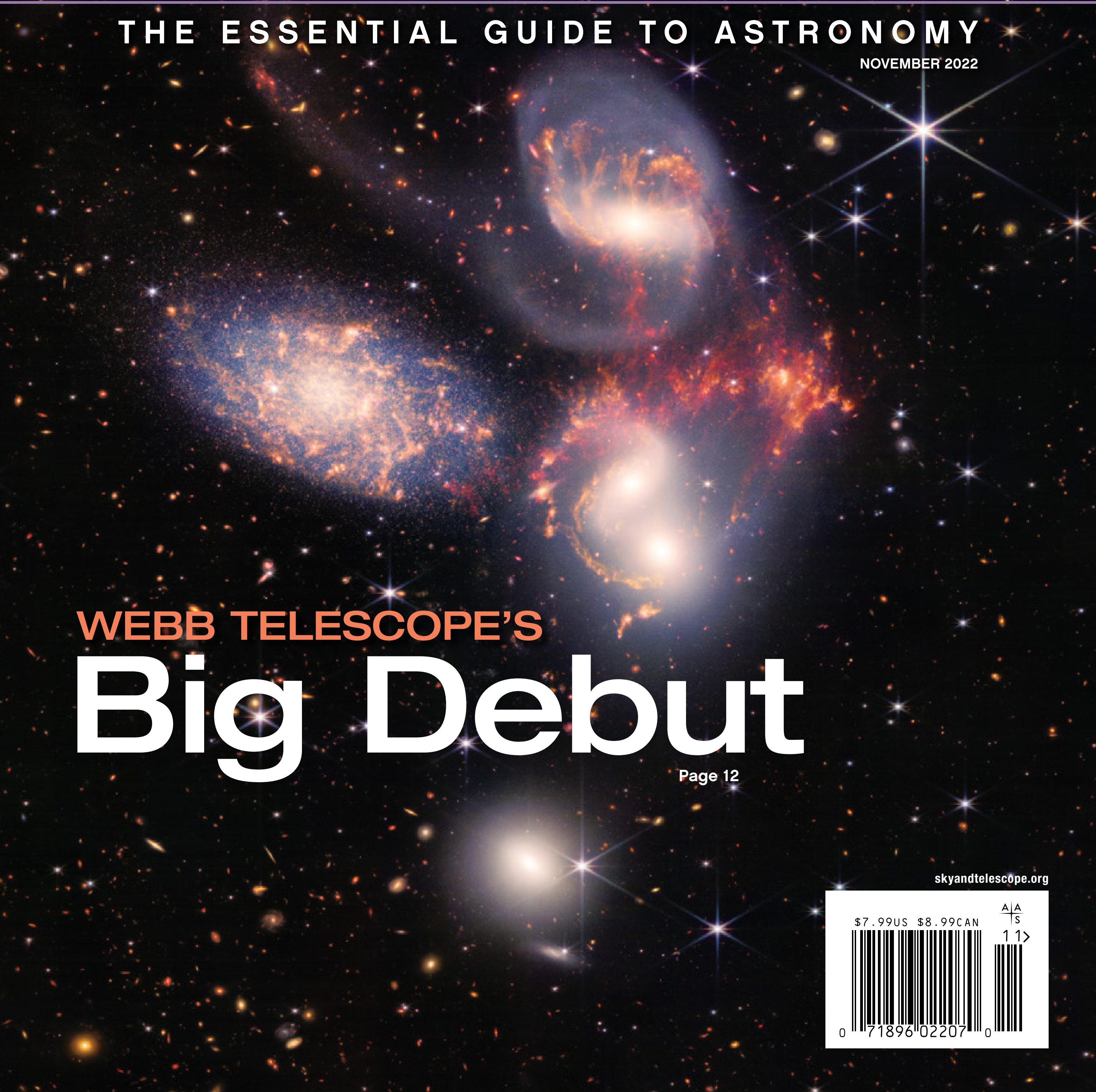

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The first data to come down from the James Webb Space Telescope demonstrate unprecedented capabilities.

A Deeper View

Since the idea of the James Webb Space Telescope (JWST) took shape around the turn of this century, the mission has had its share of naysayers. They've had their reasons: years of delays and a ballooning budget, its origami-like design, and even after deployment, an unexpectedly large micrometeoroid strike on one of its mirrors.

But the team has persisted, and now we are reaping the rewards. The testing JWST underwent during its commissioning shows that all has gone to plan, and then some. The optics are better aligned than expected, the stray light less, the images sharper — all of which mean that the telescope can go deeper faster in almost every observation. The observatory has even been fuel-efficient, with enough propellant left for at least 20 years of operations. While the better-than-hoped-for performance became apparent in commissioning, it really shone through when the mission team released the first science images.

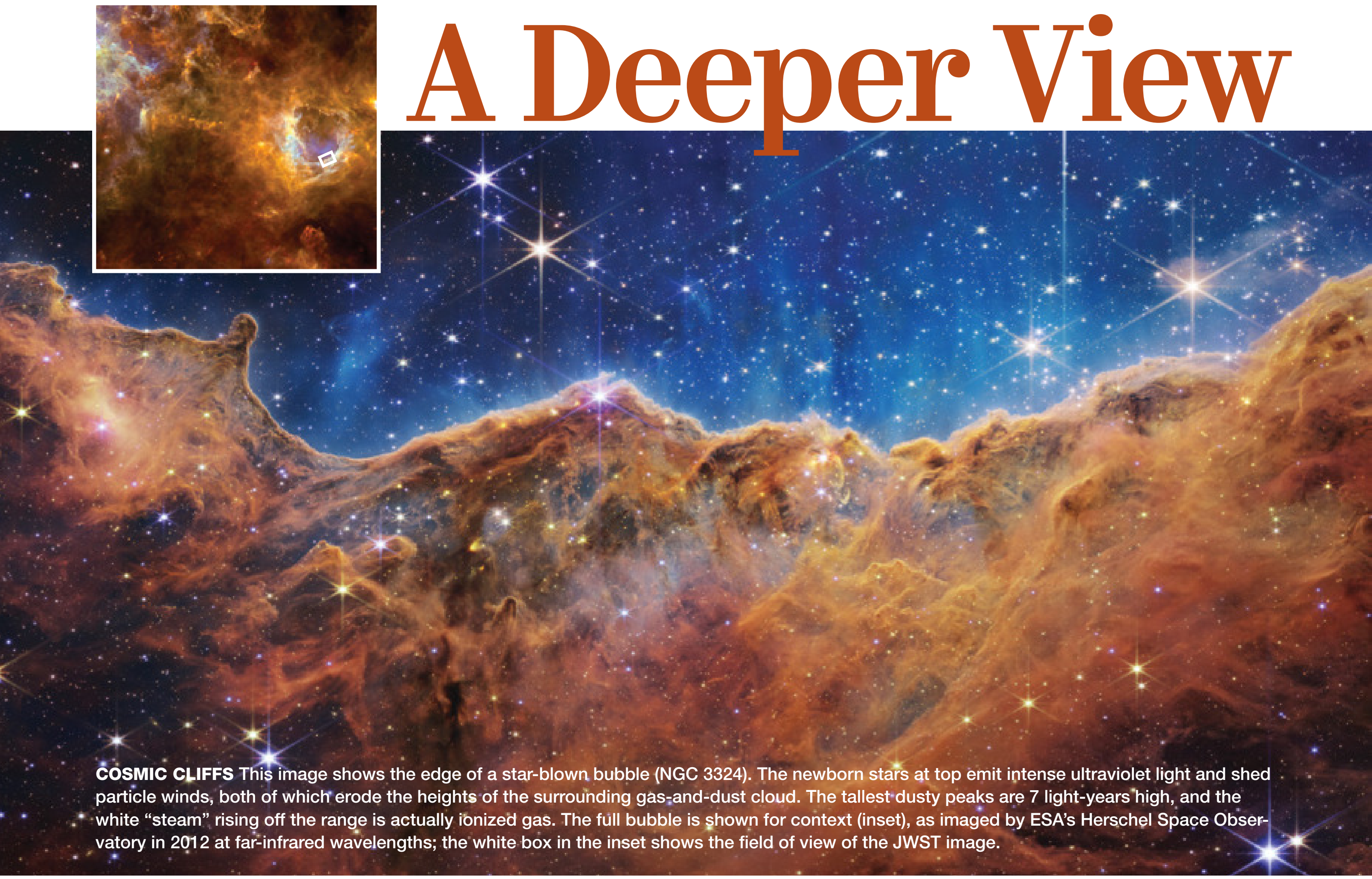
A Long Time Ago in a Galaxy Far, Far Away

Among its most impressive qualities, JWST is a time machine. The images it takes go deep into space and thus far back in time to the infant universe.

When we look at the Sun (with proper filters), we see it as it was 8 minutes ago — that's how long its light took to travel to Earth. Likewise, light from the Andromeda Galaxy was emitted 2.5 million years ago. As light travels through the expanding universe, its wavelength stretches, too, becoming redder. The Hubble Space Telescope, which explores visible and ultraviolet light, has revealed young galaxies and even a faraway star (*S&T:* Aug. 2022, p. 11), but its reach is limited. With its sharp view at longer, infrared wavelengths, JWST offers us our best hope of seeing the very first galaxies only a couple hundred million years after the Big Bang.

As the observatory kicked off science operations, it was already delivering on that promise. When NASA released its image of the massive galaxy cluster SMACS 0723, the team pointed out several galaxies from up to 13.1 billion years ago — that is, in a universe just 700 million years old.

And these are still early days: Multiple teams are already claiming the independent discovery of even more distant



COSMIC CLIFFS This image shows the edge of a star-blown bubble (NGC 3324). The newborn stars at top emit intense ultraviolet light and shed particle winds, both of which erode the heights of the surrounding gas-and-dust cloud. The tallest dusty peaks are 7 light-years high, and the white "steam" rising off the range is actually ionized gas. The full bubble is shown for context (inset), as imaged by ESA's Herschel Space Observatory in 2012 at far-infrared wavelengths; the white box in the inset shows the field of view of the JWST image.

▲ **GALAXIES GALORE** Hold a grain of sand at arm's length: That's the breadth of this tiny sliver of sky, yet it holds thousands of galaxies, many never seen before. The focus of the image is galaxy cluster SMACS 0723, whose primary constituents are the white foreground galaxies. Background galaxies appear red and yellow. The cluster's heft gravitationally lenses the background galaxies, magnifying them and distorting their shapes. The image is a composite of four infrared wavebands, or "colors," represented here as visible colors for us to see.

galaxies in the field, going back as early as 200 million years after the Big Bang. (These studies are on the arXiv preprint server but as of press time haven't yet undergone peer review.) Astronomers didn't necessarily expect early galaxies to be quite as abundant, massive, and bright as they appear to be, so the discoveries may put our theoretical ideas about galaxy formation to the test.

"We're getting as close as many scientists thought the first galaxies are," says Thomas Zurbuchen (NASA). "So, I believe we're going to get awfully close, if not really getting to the first ones."

The Last Gasps of a Dying Star

Planetary nebulae, the illuminated clouds blown out by stars collapsing into white dwarfs, have long mystified astronomers with their dazzling variety (*S&T:* Nov. 2014, p. 20). One of these celestial jewels is the Southern Ring Nebula (also called NGC 3132 or the Eight-Burst Nebula) in Vela. It's actually a biconical nebula, its shape like two bowls joined at their bottoms. However, we are viewing the bowls face on, which gives the nebula the appearance of a single ring around the center (which is where the two bowls meet).

Doppelgängers

A key signature of a JWST image is the six primary diffraction spikes on bright stars, due to the hexagonal-shaped mirrors — Hubble images have only four. Another diffraction pattern, from the struts holding the secondary mirror in place, creates a fainter horizontal bar on bright stars.

COSMIC CLIFFS: NASA / ESA / CSA / STSCI; LARGER FIELD OF VIEW FOR CONTEXT: JWST: NASA / ESA / CSA / STSCI; HERSCHEL: ESA / PACS / SPIRE / THOMAS PREIBISCH, UNIVERSITÄTS-STERNWARTE MÜNCHEN, LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN, GERMANY; MATT POVICH (CALIFORNIA POLYTECHNIC STATE UNIVERSITY); GALAXY CLUSTER: NASA / ESA / CSA / STSCI

Like many such nebulae, the Southern Ring's beauty originates in the pair of stars at its core: a bright star and a dimmer white dwarf. The dwarf emerges at mid-infrared wavelengths because of the dust that still surrounds it. While near-infrared light pierces dust, the grains themselves glow warmly at the longer, mid-infrared wavelengths. Despite its dusty shroud, the hot white dwarf lights up the nebula's center and, together with its stellar companion, stirs up the gases there.

The scene also sheds light on the birth of complex molecules in interstellar space. As the dying star gave in to gravity, it pulsed and sent out layer after layer of gas. The shed plasma cooled as it expanded, enabling grains of dust to form within it. These dusty shells dominate the mid-infrared image.

◀ **LAST GASPS** These near- and mid-infrared (top and bottom, respectively) images reveal different aspects of the Southern Ring Nebula. The central white dwarf (dimmer central star at bottom) has shed its outer envelope in a series of shuddering sighs. An edge-on galaxy (arrow) peeks through the nebula's gaseous shells.

Deep Dive into a Planet's Atmosphere

Perhaps underappreciated among the release of big, beautiful images was the spectrum of WASP-96b. This hot *super-puff* — half Jupiter's mass but still equivalent to Jupiter in size — whips around its star every 3.4 days. JWST's near-infrared *transmission spectrum* shows starlight filtered through the sliver of atmosphere visible when the planet passed in front of its star.

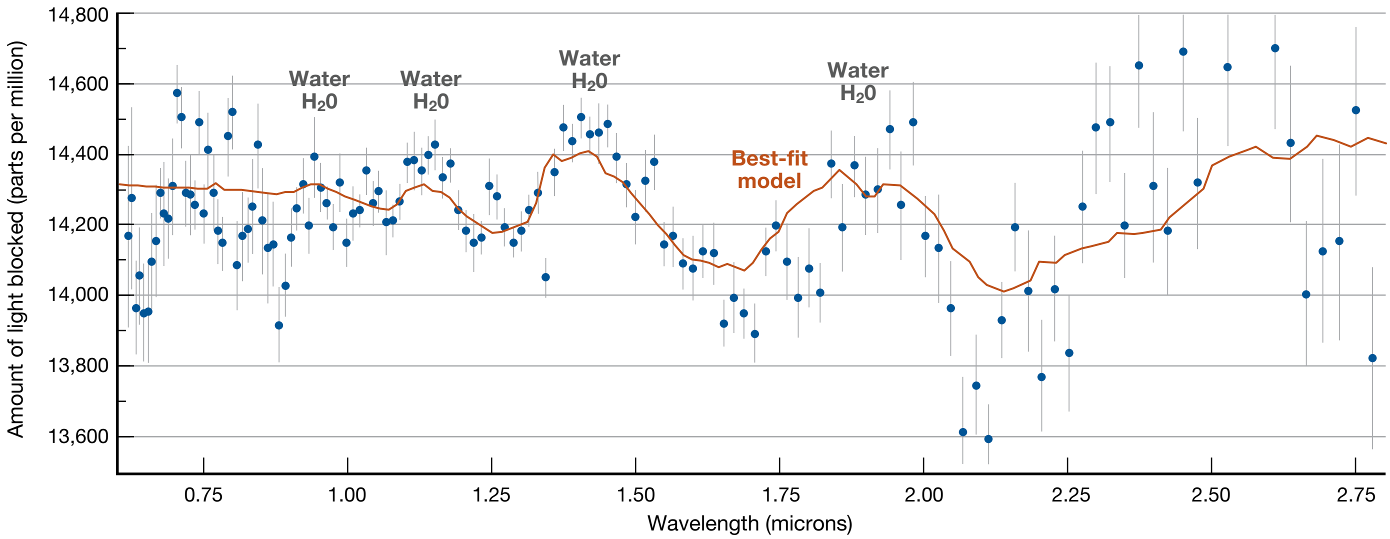
The spectrum acts as an encoded message, with bumps (absorption bands) that translate to elements and molecules present in the atmosphere. And with JWST specifically equipped for exoplanet spectroscopy, it conveys this message with unprecedented detail, as it will for many other worlds. In the case of WASP-96b, the spectrum reveals water vapor on a hot gas giant.

The presence of the molecule isn't actually surprising; astronomers expect to see water vapor in hot planet atmospheres. But while previous studies had concluded that this world is cloudless, JWST's higher-quality spectrum shows it's not: Water vapor features are weaker than expected, indicating that clouds *are* present and hiding some of the vapor-filled atmosphere from view. The slight downward slope toward shorter wavelengths could come from haze, too; firm conclusions await a full analysis.

Cosmic Cliffs

JWST's sharp infrared view also has pierced dense dust to reveal protostars in the cloud surrounding the stellar nursery NGC 3324, 7,600 light-years away in Carina.

Newborn stars populate the top of the image, their radiation and wind blowing out a bubble within their natal cloud.



▲ **HOT WATER** This spectrum captures absorption from water vapor in the atmosphere of the "hot Saturn" WASP-96b. Spanning red light (600 nm) to infrared light (2800 nm) in such a spectrum has never been done before in a single shot. The *y*-axis appears reversed (with absorption bands shown as peaks) because the star's spectrum must be subtracted from the combined spectrum to see the light that the planet has blocked. In effect, as the planet crosses its star, it appears larger in those wavelengths at which molecules in its atmosphere are absorbing the host star's light.

SOUTHERN RING: NASA / ESA / CSA / STSCI (2); EXOPLANET SPECTRUM: GREGG DINDERMAN / S&T; SOURCE: K. PONTOPPIDAN ET AL. / NASA / ESA / CSA / STSCI

STEPHAN'S QUINTET Four of these five galaxies in Pegasus are close enough to interact gravitationally; the leftmost galaxy is actually in the foreground. Infrared wavelengths showcase these interactions, which have pulled out sweeps of gas, dust, and stars (white). The central galaxy's infall has even raised a giant shock wave of hot hydrogen gas (red and gold). Barely visible diffraction spikes emanate from the brilliant center of the topmost galaxy, NGC 7319, indicating activity around the black hole in its core.

NASA / ESA / CSA / STSCI

That push instigates a new round of star formation in the dusty clouds along the bubble's edges, where stars are still in the process of coming together. At the same time, as the cloud disintegrates, star formation is coming to a halt. The image thus captures a delicate balancing act.

The youngest of the forming stars, still hosting planet-forming disks, appear as red dots in the darkest parts of the image. (In fact, JWST is finding that some of these that were thought to be singletons are actually multiples.) Look closely, and you may spot the golden signatures of the jets emitted from some of these nascent stars.

Stephan's Quintet

Of all the images JWST released in July, this one's target was the most familiar to amateur astronomers. With an infrared view, though, details never seen before become visible.

Four galaxies in this group are swiping and clashing with one another, gravitationally speaking. The infrared image shows the dust, gas, and stars flung out in these interactions as sweeping white arches. Shock waves, too, are visible as the central galaxy, NGC 7318B, crashes through the group. (The galaxy at left, 250 million light-years closer to Earth, remains unaffected by the drama.)

Galactic side-swipes and mergers can trigger bursts of star formation as well as send gas spiraling in to feed supermassive black holes at galactic centers, so that the stars and the dark core grow together. The topmost galaxy, NGC 7319, hosts such a feeding black hole, as revealed by JWST's *integral field units*, combined camera-spectrographs that take images and spectra simultaneously.

The Future Now

As this article goes to press, JWST has already taken additional stunning galaxy images and exoplanet spectra. It can do in hours what Hubble does in weeks, and we'll be hard-pressed to keep up! The infrared revolution is only beginning.

■ MONICA YOUNG is *Sky & Telescope*'s news editor.