Cosmic Collisions

by Jonathan Knight
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To a stargazer, the universe appears as placid and calm as a frozen lake. But in reality, it is a violent, churning cauldron in which galaxies explode into existence, then collide and rip each other apart, flinging debris across the cosmos. Astronomers would love to see this violence, but all they get are snapshots of galaxies in various stages of impact. To see collisions in motion, they would need a time-lapse camera that could compress a billion years into an hour.

Lars Hernquist, an astrophysicist at the University of California, Santa Cruz, has devised the next best thing: supercomputer simulations of cosmic encounters. Hernquist's computer models have helped astronomers understand the origin of starbursts, as well as estimate the quantity of dark matter that surrounds and molds galaxies. Recently, Hernquist has probed the evolution of disc galaxies like our own from their humble beginnings as diffuse interstellar gas. His models have changed the way astronomers think about the universe.

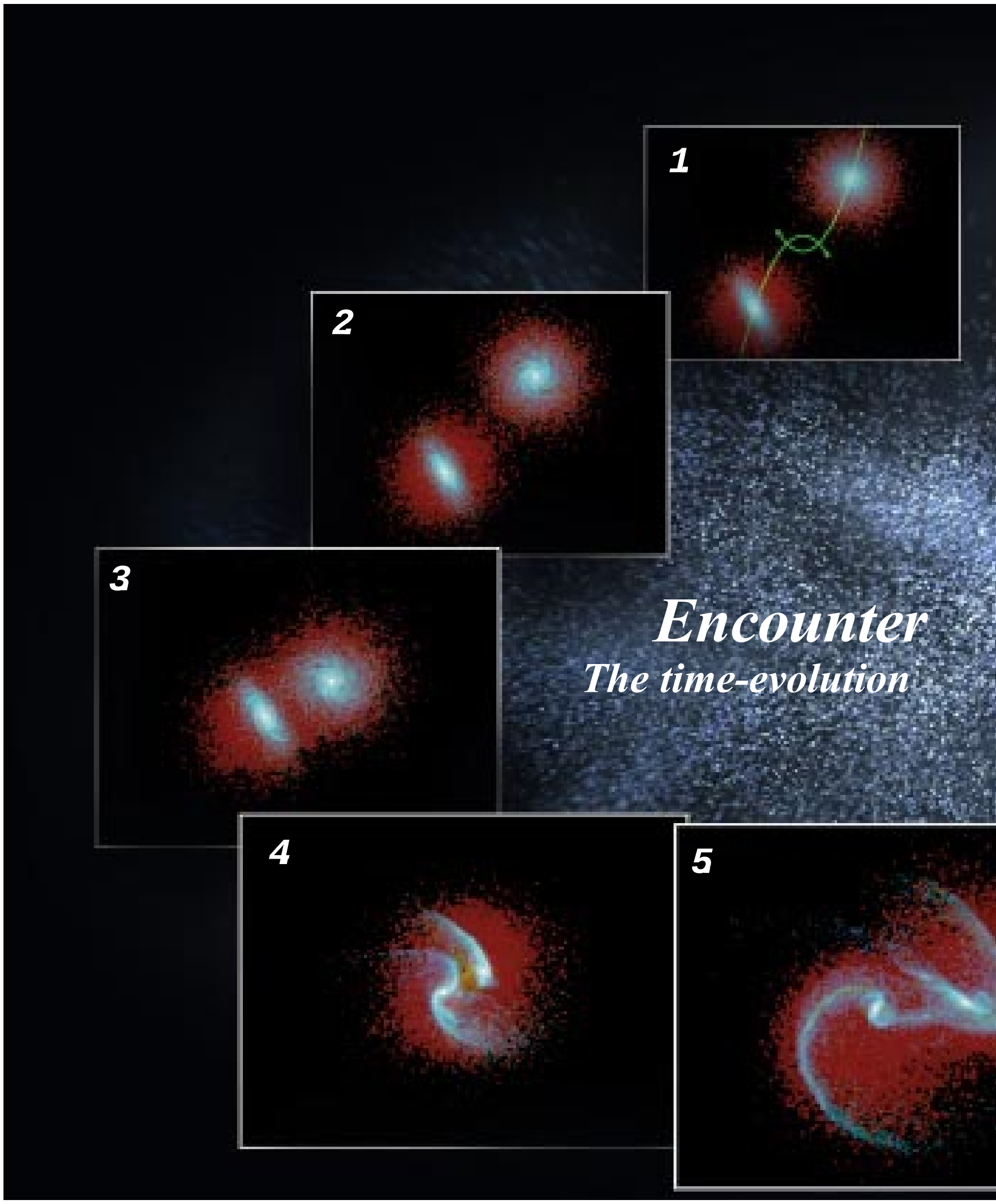
While one can argue they are mere models, simulations are the only way to watch a collision of two galaxies unfold. Astronomers have tried assembling telescopic photos of different collisions in different stages into one composite picture. But this is a bit like trying to tell what walking looks like by lining up a hundred photos of different people on a city street, each snapped from a different angle. There must be a better way.

In his office, Hernquist unrolls a poster that could be an ad for a new Star Trek movie. Above the words "Cosmic Voyage," two galaxies crash into each other in Technicolor. It's part of a simulation requiring over 1000 hours on a Cray supercomputer and including more than a million stars. The resulting one-minute video is so spectacular, it has become part of a new half-hour movie produced by the Smithsonian Institution for IMAX theaters, auditoria in which giant screens utterly immerse the viewer in light and sound."It's very nice," Hernquist says. With clasped hands resting gently on his desk, this exceedingly mild mannered man speaks about his work quietly and in monotone. But when he speaks, people listen. "He is one of the few people in astronomy who doesn't have to talk loudly to get his point across," says Johns Hopkins astronomer Chris Mihos, who collaborated with Hernquist on the Cosmic Voyage simulation.

Although the collision appears explosive in the movie, none of the stars actually meet. Instead, colliding galaxies pass right through each other. But they don't escape unscathed. As they fly by, their combined masses throw up a huge gravitational "tide." "It both squishes and stretches at the same time," says John Dubinski, a former postdoc of Hernquist's, now at the University of Toronto. "The material at the edges of the galaxies flies off like a slingshot." In a mere 100 million years, what was once a smooth disc ends up looking like a spinning lawn sprinkler.

Few IMAX-goers will notice what interests Hernquist the most about calculations like the one for Cosmic Voyage: the gas. Galaxies are full of gas. Everything from hydrogen to water vapor rotates about the galactic core along with billions of stars.But gas is hard to model. Whereas stars respond primarily to Newton's law of gravity, gas swirls around unpredictably. Think of the simple parabola traced by golf ball whacked off the tee compared to the complex path of the smoke from the golfer's cigarette. Still, physicists have inferred certain laws of fluid dynamics from experiments with gasses and liquids here on earth. Assembling these laws into elaborate computer code, Hernquist, Mihos, and Joshua Barnes of the University of Hawaii have incorporated gas into their recent simulations. One goal was to understand starbursts.

Thousands of bright starburst galaxies dot the heavens, most of which have undergone a collision in their recent history. They get their brightness from the star factories at their center, where hundreds of new stars flare into existence each year. The simulations have shown how a collision can spark a star factory. As two galaxies of unequal size meet, the gravitational tides induce a bar-shaped feature across the center of the bigger galaxy. The bar forms shock waves which knock the interstellar gas down to a lower orbit, compressing it. Squeezed tightly together, the gas molecules fuse and explode like hydrogen bombs all across the galactic core. The starburst lasts for hundreds of millions of years.

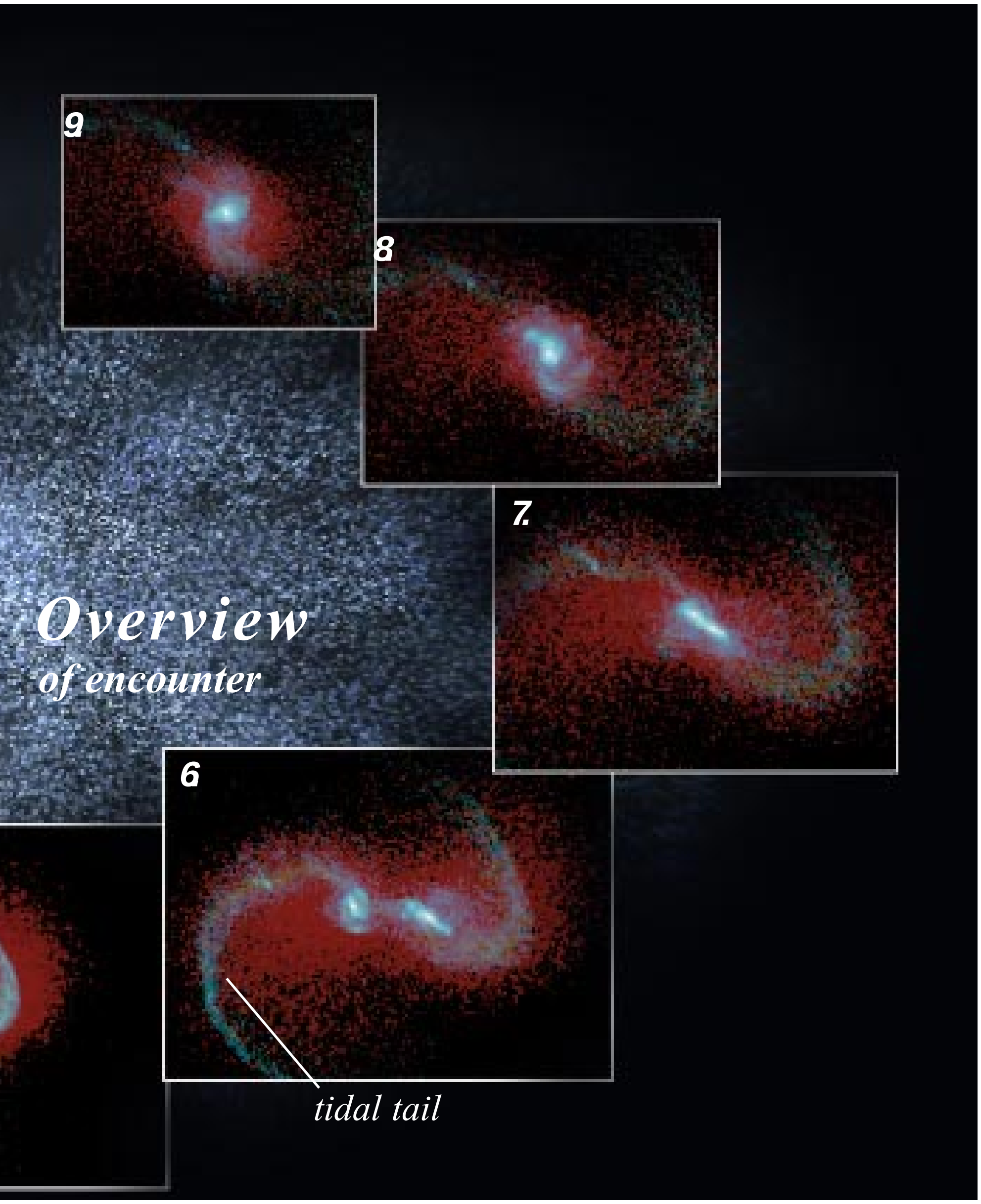


COMPUTERIZED ENCOUNTER

Two disk galaxies collide whipping up great gravitational tides that send long arms of stars (tidal tails ; 4-6) spinning into space. Unable to escape each others gravitational pull, the two galaxies soon meet again and merge.

Computer simulations have also helped answer the weighty dark matter question. Most of the mass in the universe exists as "dark matter." Otherwise invisible, dark matter reveals itself only by its gravitational effects. It may be made of subatomic particles or burnt out husks of stars, no one knows for sure. But the question of cosmic importance is how much dark matter is there? If the amount is small, the cosmos will keep expanding forever, but if the amount is large, its gravity will reverse the expansion, ultimately compressing the universe back down to a single point.

Hernquist can't answer the dark matter question for the universe, but at least around galaxies the quantity appears to be smaller than some have predicted. He and Toronto's Dubinski find that the size of the tidal tails in a simulated collision varies drastically depending on how much dark matter they put in. If a model galaxy has too much dark matter, the gorgeous arching tails seen in the telescope can't form, suggesting that the amount of dark matter in galaxies is small. Perhaps the universe has a future after all.



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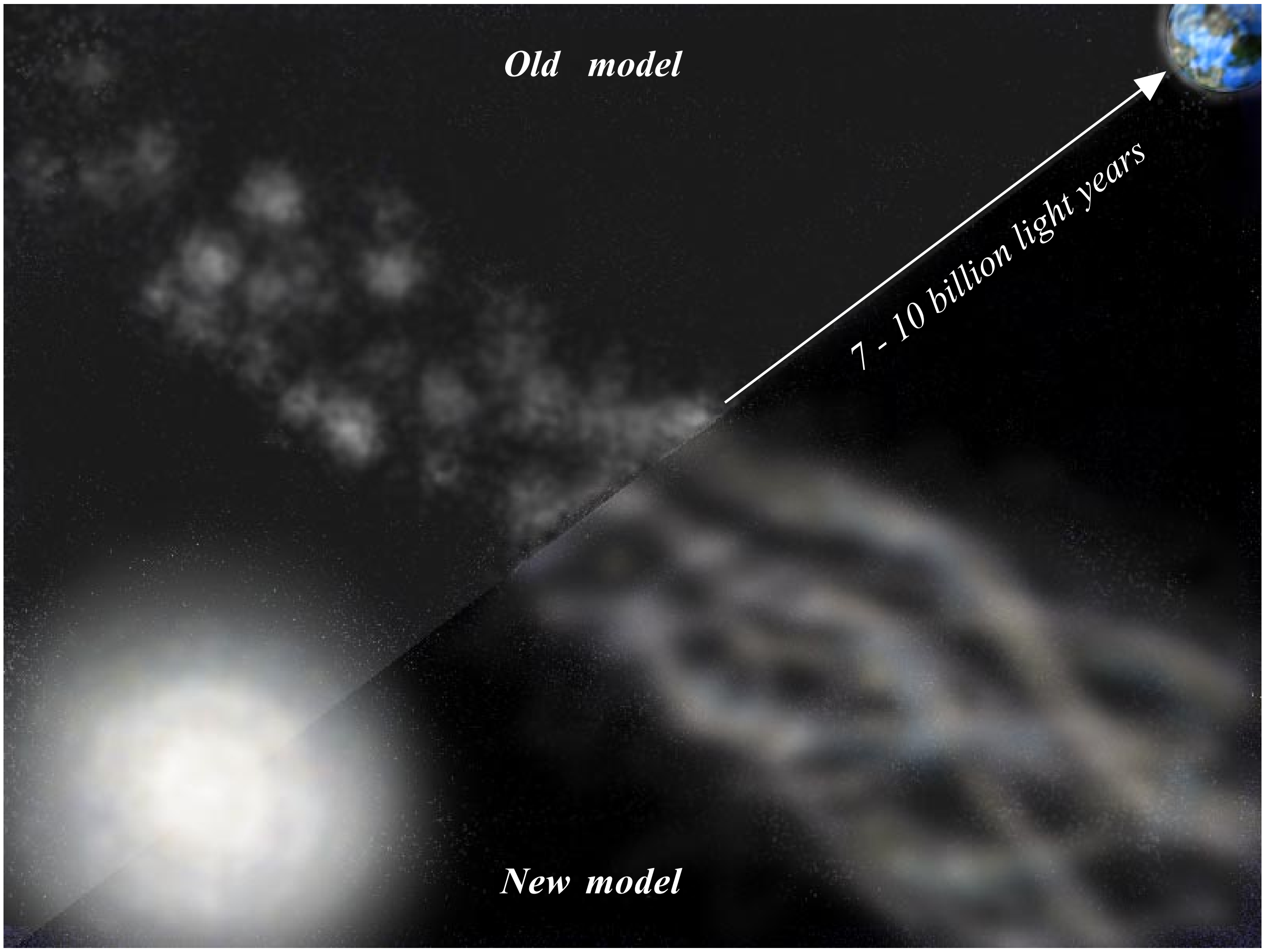
The entire encounter takes 100 million yaers. *Here dark halo matter is shown in red, bulge stars are shown in yellow, disk stars are shown in blue, and the gas is shown in green.*

Whatever the future holds, Hernquist would also like to know about the past. Recently he has turned his attention to a mysterious corner of the universe called the Lyman alpha forest. This forest of gas, which harbors clues to the formation of galaxies like our own, is so dark and distant that astronomers can't see it directly. But thanks to intensely bright quasars that shine through the gas like flashlights, they can see the forest's shadows.

As the quasar light streams through the Lyman alpha forest, the gas absorbs certain wavelengths. By splitting the light into a rainbow with an ultra-fine prism, astronomers reveal a series of black lines across the spectrum. These are the shadows of hydrogen gas. Because of the time it takes the light to reach the earth, these shadows were cast around seven billion years ago, before most modern galaxies had formed.

We know a lot about the forest. As the gas hurtles away from us through space, it shifts the position of the dark lines in the spectrum towards the red by stretching out the light waves, just as a passing car stretches its sound waves, producing a deeper rumble as it heads away. By discerning differently red-shifted hydrogen lines in the spectrum, astronomers can tell that the gas in the Lyman alpha forest is not homogeneous, but grouped into clumps, some further away and traveling faster than others. For years astronomers supposed those clumps of gas to be shaped like clouds, which would have insufficient mass to ignite galaxies.



GAS MODELS
A schematic view of two models of the distribution of gas in the Lyman alpha forest. Clouds (top half) or sheets (bottom half) of hydrogen and other gasses absorb light from quasers (bottom left) on its 5 to 7 billion year journey to Earth.

Now Hernquist and David Weinberg of Ohio State University have modeled the forest and have found something totally different, not like clouds at all. They start the simulation around a billion years after the Big Bang, when, according to theory, gas was spread evenly in space. After the simulation evolves for several billion years, the gas condenses, not into clouds, but into giant sheets and wispy ribbons. Could this be what the Lyman alpha forest looks like? By shining a computer-generated quasar through the gas model, Hernquist and Weinberg compare the model's shadows to the real shadows from the Lyman alpha forest. The match is nearly perfect.

Intellectually, thinking of the forest as sheets of gas rather than clouds is more satisfying. For one thing, continuous gas could provide enough mass to form galaxies. Furthermore, galaxies in more recent parts of the universe occur in layers, as if they had formed in overlying sheets. Indeed, the cybergas itself continues to condense as the simulation runs on toward the present, until, at points of high gas compression, galaxies explode out of the vapor. Hernquist and Weinberg have apparently modeled seven billion years of cosmic evolution.

Some caution is always appropriate when interpreting simulations. "It's very tricky in this game not to get carried away by shaky results, but not to be so cautious that you don't learn anything," Weinberg says. "What Lars does well is tread that line."

As a result, most of his colleagues accept Hernquist's interpretations. "Five years ago," Hernquist says, "if you asked people what this gas between us and the quasars looks like, most would have pointed to some of the simple models that had been around for thirty years. If you asked most of the observers and theorists now what they believe, it is based pretty much on these computer simulations. This new point of view has taken over." □