Anglo-Australian Telescope in Coonabarabran, Australia, is halfway through its attempt to map 250,000 galaxies. The distribution of those galaxies depends crucially on events in the very early universe. For a few hundred thousand years after the big bang, matter and energy were a seething plasma, ringing with the concussion of the cataclysmic explosion. Pressure waves rattled through the plasma, compressing matter, letting it expand, and compressing it again. As the universe grew and cooled, the compressed regions gave rise to massive clusters of galaxies, while the rarefied ones stayed relatively free of matter. So by looking at the distribution of galaxies and voids, astronomers can figure out what the acoustic waves in the early universe were like, just as they can with the distribution of peaks and dips in the strength of the cosmic background radiation (*Science*, 28 April 2000, p. 595; 19 January 2001, p. 414).

Different types of matter, however, transmitted those pressure waves in different ways. Ordinary baryonic matter would have compressed and expanded very strongly, as it was constantly being slammed about by the radiation pressure. "Exotic" dark matter —the kind believed to consist of so-far-undetected particles—would have oscillated more weakly, as it barely interacts with radiation. (That's what makes it invisible to telescopes.) Thus, wiggles in the distribution of galaxies—bumpy features in the graph that describes clumps of matter and voids on various scales—can reveal how much of the primordial matter was baryonic.

"When you make plots, you do see bumps, hills, and valleys," says Cambridge University astrophysicist Ofer Lahav, a member of the 2dF team. "When we all first saw the pictures, we were very excited." Although Lahav advises caution in interpreting such preliminary results, he says the measurements indicate that baryonic matter in the early universe weighed in at 5% of the mass needed to give space the shape that cosmologists prefer. That's smack-dab between the 4% based on theories of how atomic nuclei were generated in the early universe and the 6% implied by measurements of cosmic background radiation.

The 2dF data collected so far aren't strong enough to settle any cosmological arguments. University of Chicago astrophysicist Michael Turner thinks the results are intriguing but reserves judgment for the moment. "What's great about cosmology now is that the results are just going to get better," he says. "We don't have to debate each other until we're blue in the face. There's more data coming." Further observations by the survey and the rival Sloan Digital Sky Survey could provide a more definitive answer within the year. **—CHARLES SEIFE**

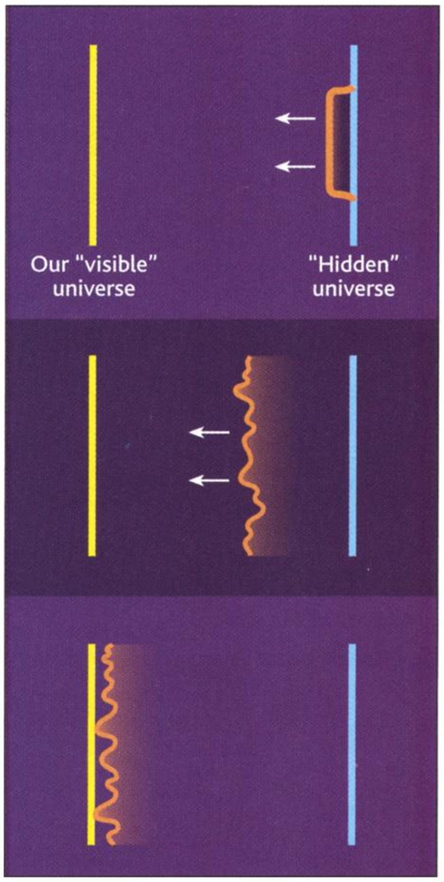
COSMOLOGY

Big Bang's New Rival Debuts With a Splash

BALTIMORE, MARYLAND—Will the big bang make way for a big splat? It might, if a new idea by four cosmologists catches on. Their theory, posted online* and unveiled here last week in a surprise talk at the Space Telescope Science Institute, provides what other scientists are calling the first credible alternative to the reigning big bang model and its long-standing add-on, inflation.

"It's a neat idea. In a way, we didn't have any competitors to inflation until now," says David Spergel, an astrophysicist at Princeton University. "I'm more comfortable at the moment with inflation, but that's probably because I've lived with it longer."

Inflation theory has been cock of the walk since the early 1980s, when physicist Alan Guth concocted it to solve several problems that had been plaguing big bang theorists. For instance, the universe appears to be "flat" (a technical term describing the large-scale curvature of space) and has roughly the same properties everywhere—features that a simple big bang model can't easily explain. Inflationary theory proposes that the very early universe went through an amazingly violent and rapid expansion for less than 10^{-32} second, which gave the universe precisely the flatness and isotropy that we see today. Almost every cosmologist accepts inflation, and for 20 years no one has come up with a new scenario that so well matches scientists' observations.



Splatter film. In the ekpyrotic model, a four-dimensional scrap of another universe wrinkles as it floats through 5D space, then stamps our universe with a mix of long-range regularity and small-scale disorder.

ILLUSTRATION: A. STONEBRAKER

"This is a fairly ambitious project," admits Princeton physicist Paul Steinhardt. Along with his student Justin Khoury and physicists Neil Turok of Cambridge University and Burt Ovrut of the University of Pennsylvania in Philadelphia, Steinhardt has created what they call the "ekpyrotic model": a version of the early universe that explains flatness and isotropy without invoking inflation.

At first glance, the new model—based on an extension of string theory known as M-theory—seems surreal. It takes place in 11 dimensions, six of which are rolled up and can safely be ignored. In that effectively five-dimensional space float two perfectly flat four-dimensional membranes, like sheets drying on parallel clotheslines. One of the sheets is our universe; the other, a "hidden" parallel universe. Provoked by random fluctuations, our unseen companion spontaneously sheds a membrane that slowly floats toward our universe. As it moves, it flattens out—although quantum fluctuations wrinkle its surface somewhat—and gently accelerates toward our membrane. The floater speeds up and splats into our universe, whereupon some of the energy of the collision becomes the energy and matter that make up our cosmos. Because both the moving membrane and our own membrane start out roughly flat, our postcollision universe remains flat as well. "Flat plus flat equals flat," says Steinhardt.

Because the membrane floats so slowly, it has a chance to equilibrate, giving it more or less the same properties over its entire surface, although the quantum fluctuations cause some irregularities. That explains our universe's roughly (but not exactly) isotropic nature. But whereas inflation solves the problems of flatness and isotropy by a quick, violent process, Steinhardt points out, "this model works in the opposite sense: slowly, but over a long period of time." Another attractive feature is that it gets rid of the singularity at the beginning of the universe: Instead of a pointlike big bang, the universe is formed in a platelike splash.

* arXiv.org/abs/hep-th/0103239

"It's the first really intriguing connection between M-theory and cosmology," says Spergel. "This is sort of an Ur–big bang." And although ekpyrotic theory might seem like an import from cloud-cuckoo-land, future real-world experiments should be able to tell whether it or inflation is correct. The two models send different sorts of gravitational waves rattling around the universe—waves that might one day be detectable by successors to current gravitational-wave experiments.

Experimental verification might take a less welcome form. The model's name, Steinhardt explains, comes from the Stoic term for a universe periodically consumed in fire. That is because at any moment another membrane could peel off, float toward us, and destroy our universe. Indeed, Steinhardt says, we might have already seen the signs of impending doom. "Maybe the acceleration of the expansion of the universe is a precursor of such a collision," he says. "It is not a pleasant thought."

–CHARLES SEIFE

PALEOCLIMATOLOGY

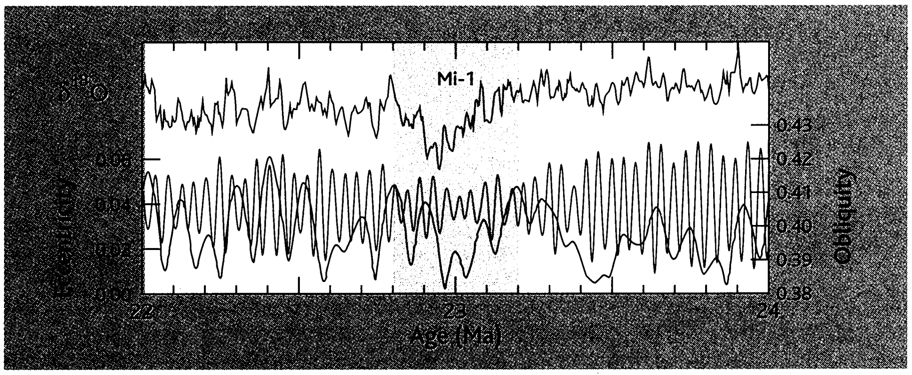
An Orbital Confluence Leaves Its Mark

Whenever they could, the 19th century geologists who split time into epochs chose as a boundary a grand transformation of the period's dominant animal group. But some intervals dragged on for so long without an appropriate transformation that geologists chose another marker to break them up. For the division between the Oligocene and the Miocene, they picked an episode of sediment erosion. At the time, nobody knew its ultimate cause. Now, paleoceanographers have finally put their finger on it—and in the process, they've identified a new way to make an ice age.

On page 274 of this issue, paleoceanographer James Zachos of the University of California, Santa Cruz, and colleagues report that 23 million years ago a rare combination of the shape of Earth's orbit and the tilt of its rotation axis led to a brief climatic cooling and buildup of ice on Antarctica. This, in turn, lowered sea level and exposed the shallow sea floor to erosion, creating the Oligocene-Miocene boundary. The convergence of orbital variations would be "a very reasonable explanation" for the glacial boundary event, says paleoclimate modeler Thomas Crowley of Texas A&M University in College Station, as well as further support for the power of orbital variations to influence climate.

New insights into climatic events of the Oligocene-Miocene transition come from sediment laid down between 20 million and 25.5 million years ago in the western equatorial Atlantic and retrieved in two Ocean Drilling Program cores. From these two cores, Zachos and colleagues extracted complete, finely detailed records of two sets of stable isotopes preserved in the carbonate skeletons of microscopic bottom-dwelling animals called foraminifera. The changing ratio of oxygen-18 to oxygen-16 along a core reflects varying bottom-water temperature as well as changes in the volume of glacial ice in the world. The ratio of carbon-13 to carbon-12 reflects changes in the geochemical cycling of carbon, in this instance most likely due to changes in the productivity of ocean plants. Zachos and colleagues going of the ice ages tied to changing eccentricity. In the case of tilt, the connection between orbital variation and climate is straightforward—when the planet tilts far over, high-latitude land gets extra sunlight and warmth in the summer, discouraging the year-to-year accumulation of snow that would otherwise form ice sheets. When tilt is low, there's less summer sunlight in the high latitudes and glaciation picks up.

Inspecting the entire 5-million-year record, Zachos and colleagues found one geologic moment when the orbital forces for climatic cooling and ice sheet building came together. At 23.0 million years ago, eccentricity dropped to low levels and variations in tilt



Two wiggles make an ice age. The cyclic nodding of Earth on its rotation axis (red) nearly steadied 23 million years ago and the periodic elongation of its orbit (eccentricity, blue) nearly disappeared, leading to an ice age (dip in black curve).

CREDIT: J. ZACHOS *ET AL.*

developed a time scale by matching cyclic variations in core sediment properties, such as color, to changes in the shape or eccentricity of Earth's orbit and in Earth's axial tilt, each of which keeps a steady orbital beat through the ages. Then they applied this scale to their isotope records.

The time scale allowed them to determine the pace of climate and carbon-cycle changes. Now they could compare the timing of events on Earth with that of orbital cycles. They found that ocean climate throughout the 5-million-year record varied in step with orbital variations, from the 400,000-year and 100,000-year variations in orbital eccentricity to Earth's 41,000-year nodding as it changes tilt. And the strength of the climate response varied in proportion to the strength of the orbital variation, especially in the case of the 100,000-year variation. Such strict correlation, with climate lagging slightly behind orbital variations, convinced them that the orbital variations were altering climate back then. When eccentricity was low, climate cooled. It also cooled when tilt steadied to only modest variations without excursions to high tilt.

Those are the same climate-orbit relations invoked to explain climate change during the past million years, including the coming and nearly disappeared. Simultaneously with these ideal orbital conditions for ice sheet formation, bottom waters cooled and ice volume increased. An ice age had arrived, at least by the standards of a time when ice was typically limited to modest amounts on Antarctica. When the orbital confluence disappeared, 200,000 years later, so did the extra ice. The excursion into deeper glaciation may have been helped along, they say, by a preceding million-year-long decline in the greenhouse gas carbon dioxide that is suggested by the trend in carbon isotope composition.

Researchers are pleased that there's more to the Oligocene-Miocene boundary than a conveniently timed gap in sedimentation. "It's a fabulous data set," says paleoceanographer Kenneth Miller of Rutgers University in Piscataway, New Jersey. The coincidence of an "orbital anomaly"—simultaneous extremes of two different orbital variations—and a major climate event suggests a new way for orbital variations to trigger climate change, says Crowley. "The idea that 'cold' summer orbits drive you into glaciation and 'hot' summer orbits drive you out is one of the linchpins" of the orbital theory of climate, he says. At the Oligocene-Miocene boundary, climate seems to shift under an orbital double whammy.

–RICHARD A. KERR