tion with TIGR scientists, completed the *Treponema* genome last year, they noticed that its DNA contains genes for two particular ATPases—enzymes that break down adenosine triphosphate, often to release energy—known before to exist only in the archaea. And *Treponema* also has other genes that look suspiciously archaeal in origin, he reported at the microbial genomes meeting.

Revising history

In an upcoming issue of *Trends in Genetics*, Ford Doolittle proposes a new mechanism for this kind of gene swapping. He suggests that early eukaryotes may have gotten a significant part of their genomes from genes picked up by their predecessors from their food. As he puts it, "You are what you eat."

Assuming that the current tree of life is correct, he asks, how else can one explain Russell Doolittle's conclusions that 17 of 34 families of eukaryotic proteins that date back to early cell evolution look as if they come from bacteria, while only eight show a greater similarity to archaea, the supposed ancestor of eukarya. Terry Gasterland's team at Argonne National Laboratory, outside Chicago, Illinois, has made a similar finding: Twice as many yeast nuclear genes match up with bacterial genes as with archaeal genes.

Although some modern bacteria are quite adept at taking up new genes—many pathogens develop antibiotic resistance this way—the successful incorporation of genes from food bacteria into eukaryotic genomes would be accidental and infrequent. But "we've got hundreds of millions of years for it to happen," Ford Doolittle points out. Also, these genetic morsels are consumed with each meal, so that an incoming gene can have many opportunities to get into the genome and replace its native counterpart. In contrast, once a native gene happens to get removed from the host's genome, "it's lost forever," he adds. Over evolutionary time, these processes would favor the loss of native genes and their replacement with borrowed ones.

Woese thinks gene swapping was rampant even among life's earliest organisms. In his view, the organisms that lived before archaea, eukarya, and bacteria went their separate ways lived communally. "It was more like a consortium," Woese says of this very early world. The ability to make use of a neighbor's genes would have proved an important advantage, he asserts.

Members of this consortium may even have had different genetic codes. But the organisms that outlasted the rest would have been those that could make use of their neighbor's genes to adapt to changing conditions, says Woese. Over time, this advantage "ensured that the [DNA] code was universal," he says, because those not able to read DNA-based genes could not survive as well as those organisms using DNA.

This prehistoric commune might have worked well for early life, but it adds to the challenge for biologists trying to make sense of it all. With each descendent from this community "having taken up different things from the ancestor, you won't be able to draw clear trees," Woese points out. He still has faith, however, that organisms roughly followed the patterns of evolution seen in changes in rRNA and that the three kingdoms will remain intact.

However, the existence of so many genes that seem out of place has led some researchers to question whether eukarya descended from archaea. These researchers are also wondering whether archaea really are distinct from true bacteria, noting that although archaea were once considered limited to extreme environments, they are also turning up in the milder surroundings favored by true bacteria (*Science*, 24 April, p. 542). "I think it's open whether the three domains will hold up," says Feldman.

Despite the current ferment, however, Woese and others are confident that eventually a consistent picture of microbial evolution will emerge—even if what it might look like is uncertain, and even if its base is the mix of communal organisms Woese envisions. Within a year, some two dozen more genomes will be complete. At the same time, new software programs are refining researchers' ability to trace the heritages of different genes and discover more links between the three kingdoms. All this, says Texas's Norris, "will lead to a much better understanding of evolution as a whole."

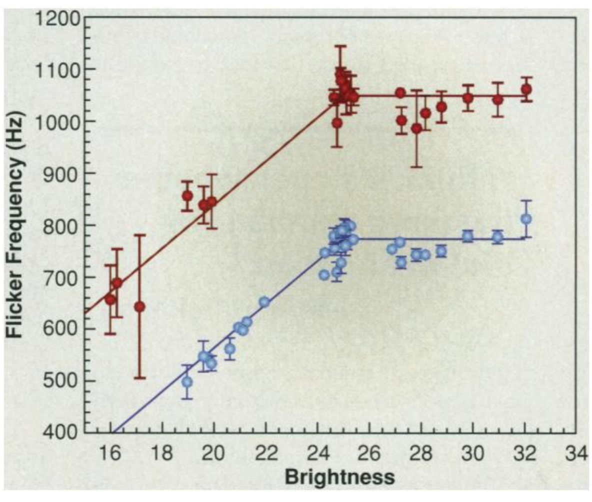
–Elizabeth Pennisi

ASTROPHYSICS

X-ray Flickers Reveal a Space Warp

If Earth had no atmosphere and no mountains, a satellite could orbit the planet at treetop level without falling. But Einstein's theory of gravity predicts that a very dense body, such as a black hole or a neutron star, bends space so steeply that objects orbiting closer than a certain point would slide catastrophically inward. Now x-ray signals from a distant neutron star have offered the first strong evidence for this smallest stable orbit. The findings, presented at a meeting of the American Physical Society in Columbus, Ohio, last week, offer a rare test of Einstein's theory in a strong gravitational field. They also offer new clues to the workings of these x-ray beacons.

Neutron stars are only about 20 kilometers across, but they contain more mass than our sun. (Someone standing on the surface would weigh over a trillion kilograms.) In 1996, NASA's Rossi X-ray Timing Explorer satellite picked up rapid-fire x-ray flickers coming from some of these distant heavyweights. Most astronomers believe that the fastest flickers come from a long stream of material that spirals down to the star's surface from the innermost edge of a spinning "accretion disk," producing a splash of x-rays. The x-rays emerge from the point where the material spills into the star. That point moves around with the accretion disk, so the x-rays rotate past Earth like a beam from a lighthouse.



Topping out. Two sets of x-ray pulses track the speed of material orbiting a neutron star. The pulses brighten as the material creeps inward, but a frequency cutoff reveals a closest possible orbit.

SOURCE: W. ZHANG *ET AL.*, *ASTROPHYSICAL JOURNAL LETTERS*

The flicker frequency rises whenever the inner edge of the disk creeps closer to the star and whips around it even faster. This may happen when a big chunk of material happens to fall in, throwing up a flare of x-rays but blocking some of the neutron star's radiation, which keeps the disk at bay.

Hoping to spot the innermost orbit, astronomers spent a year watching a neutron star called 4U 1820-30 with the Rossi satellite. The group, from the NASA Goddard Space Flight Center in Greenbelt, Maryland, clocked the frequency of the beacon and watched its brightness, which told them how much material was falling in. As expected, when the beacon got brighter, the frequency increased. Then, to their delight, the brightness increased, but the frequency seemed to hit a ceiling at about 1000 cycles per second. It would go no higher, implying that no smaller orbit was possible.

The group measured the ceiling on four different occasions, and they also saw it in a second, slower flicker, which originates as the accretion disk signal modulates another x-ray signal from a hot spot on the surface of the spinning star. "I'm convinced it's not a fluke," says NASA Goddard's William Zhang, who presented the findings. Zhang says the innermost orbit is about 20 kilometers from the star's center.

"These are extremely exciting results," says Massachusetts Institute of Technology (MIT) physicist Paul Joss, explaining that the innermost orbit is direct evidence of the drastic warping of space-time expected near a massive object. Similar observations, says MIT physicist Wei Cui, could provide a stringent test for Einstein's theory. "Everyone assumes relativity is right," he explains, "but there are so many theories of gravity around."

Most of these variants of relativity are indistinguishable from Einstein's except around dense objects like neutron stars. The innermost orbit, "literally a few kilometers above this strange object," he says, is just the place where the theories' predictions might differ. If Einstein's theory is right, the position of the innermost orbit means the star's mass is about 2.3 times that of the sun. Unfortunately, there are no independent measurements of the mass to test that conclusion. But by studying other x-ray emitters, physicists may be able to confirm Einstein or rule out his competition.

Relativity specialists aren't the only ones delighted with the data. The position of the innermost orbit implies that the neutron star is surprisingly hefty. By some estimations, that much mass packed into so small a volume should have collapsed into a black hole. The fact that it hasn't means that the strong nuclear force holding the particles apart is stronger than some had expected. "The nucleons want to stay farther away from each other," staving off further collapse, says NASA Goddard physicist Jean Swank.

University of Illinois astrophysicist Frederick Lamb is delighted with another feature of the data, the correlation between brightness and frequency. It supports his contention that the star's radiation plays a crucial role in controlling the infall of matter. "These data are like a dream come true," he says. But he cautions that they "have only been around for 2 weeks. We need to kick the tires and see that they stand up."

–David Kestenbaum

EVOLUTIONARY BIOLOGY

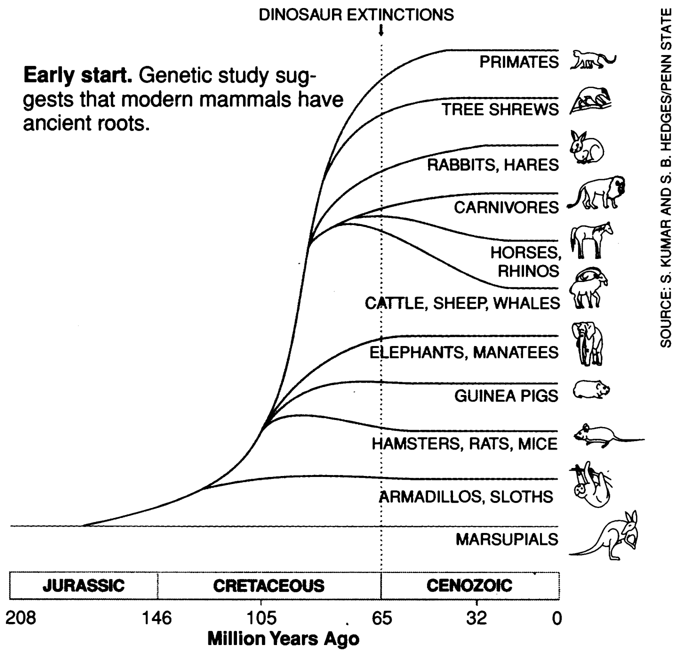
Genes Put Mammals in Age of Dinosaurs

It's hard to imagine humbler beginnings than those usually assigned to mammals. The long-standing view from the fossil record is that our furry ancestors first appeared 225 million years ago as small, shrewlike creatures living in the shadow of the dinosaurs. Only after a mass extinction 65 million years ago at the end of the Cretaceous period killed off the dinosaurs were mammals able to evolve into everything from primates to rodents to carnivores. But a new genetic study is challenging that view, saying mammals were already a diverse lot during the age of dinosaurs.

In this week's issue of *Nature*, evolutionary biologist S. Blair Hedges and molecular evolutionist Sudhir Kumar of Pennsylvania State University, University Park, describe how they compared genes from hundreds of vertebrate species and used the differences as a molecular clock to date when animal lineages originated. The molecules show, say Hedges and Kumar, that the modern orders of mammals go back well into the Cretaceous period, in some cases to more than 100 million years ago. "The thought of all these different creatures living under the feet of the dinosaurs is intriguing," says Hedges.

But many paleontologists are deeply skeptical. "It suggests that the fossil record is horribly incomplete," says Michael Benton, a paleontologist at the University of Bristol in the United Kingdom. "They're saying side by side with lower Cretaceous dinosaurs, we should be finding ducks and hens and squirrels and rabbits." Instead, he thinks that the molecular clock can't keep time.

The new report is the latest of several molecular studies to suggest that many animal lineages are older than the fossil record shows (*Science*, 21 February 1997, p. 1109). Most of these studies have relied on just a handful of genes and have not persuaded many doubters. But Hedges and Kumar analyzed a prodigious number of genes—658 in all—and counted sequence differences between 207 vertebrate species. They assumed that the more differences between two species, the more time had passed since they diverged from a common ancestor. To calculate how fast the molecular clock ticks, the team started with a reliable date from the fossil record: 310 million years ago, when the mammal-like reptiles split from the birdlike reptiles. From the sequence differences seen between animals in these two groups, the team calculated a rate of change for each gene, then used those rates to calculate divergence times among other species of vertebrates.



Early start. Genetic study suggests that modern mammals have ancient roots.

For most species, the molecular dates matched those from fossils—but not for mammals. According to the genes, the modern orders of mammals arose much earlier than expected (see graph). Marsupialia (kangaroos and opossums) are pegged as originating 173 million years ago, rather than 94 million years as indicated by fossils, and Archonta (primates and tree shrews) at 86 million years ago, rather than 64 million years ago. "This doesn't mean that elephants and tigers were running around," says Hedges. "The animals themselves were probably small. But the lineages leading to different modern orders of mammals were already distinct."

Paleontologist Philip Gingerich of the University of Michigan, Ann Arbor, however, protests that if the molecules are right, the fossil record has a gap as big as 70 million years. "You can imagine how maddening this stuff is to a paleontologist," he says.

The missing mammals may have been overlooked because they were small and harder to find, or because they were scarce and lived in terrain less likely to be preserved, suggests Hedges. But Benton says that's unlikely because the Cretaceous fossil record reveals many lizards, snakes, birds, and other small vertebrates. And paleontologists have turned up