Photon drag: New spin on making a black hole

Some galaxies have a heart of fire, a center so luminous that it outshines the rest of the starlit body. Most astronomers believe that a black hole fuels the fireworks at the core of such galaxies, known as active galactic nuclei. But astrophysicists are uncertain how a massive black hole – an object that represents the extreme of gravitational collapse – could form, especially so early in the history of the universe.

Though black holes may be exotic, one of the puzzles in understanding their creation lies in ordinary physics, notes Abraham Loeb of the Institute for Advanced Study in Princeton, N.J. Early in the universe, random fluctuations in the density of matter may have prompted some huge gas clouds to begin collapsing. But long before becoming a black hole, a cloud's own rotation, or angular momentum, would halt the process. Just as Earth's rotation provides a centrifugal force that prevents our planet from falling into the sun, the swirling motion of the cloud prohibits complete collapse.

In order to form a black hole, the cloud must lose much of its angular momentum. Ordinary viscosity, caused by collisions between particles in the gas, won't suffice, Loeb says. But in the Feb. 1 ASTROPHYSICAL JOURNAL, he suggests a possible solution to the problem.

Loeb notes that the cosmic background radiation – photons left over from the universe's explosive birth – had a high density in the young universe. He calculates that the interactions of these photons with electrons or dust in a gas cloud could produce a drag force, slowing the rotating cloud. Like a falling water droplet that encounters resistance from surrounding air molecules, electrons and dust in the cloud lose energy as they scatter off the cosmic photons inside the cloud. Loeb says that the collisions may significantly reduce the cloud's angular momentum, enabling a black hole to form.

Photons may also play an important role later on, after the cloud has succeeded in forming a black hole and outside matter begins spiraling in, forming an accretion disk around the condensed mass. To fall into the hole, this matter must also lose angular momentum. Cosmic photons can't do the job, since their density is too low at later times in the expanding universe. However, the quasar-like radiation emitted just outside the black hole as previous matter fell into it may provide the answer, Loeb says.

As the quasar photons stream outward, they slam into electrons, enabling the radiation to carry angular momentum away from the interior of the accretion disk. This allows material robbed of its angular momentum to fall into the hole, Loeb suggests. As this material gets sucked in, it emits light and the process repeats. Loeb estimates that this photon-electron interaction increases the viscosity of gas in the accretion disk to about a trillion times that of water.

In this model, a black hole and the quasar powered by it are created first; surrounding gas eventually forms a galaxy around them. But astronomers don't yet know if this sequence is correct, in part because visible-light studies don't easily permit searches for extremely distant quasars – those that might have been born before the universe attained even 7 percent of its current age.

Loeb proposes in an upcoming ASTROPHYSICAL JOURNAL LETTERS that a highly sensitive array of radiotelescopes, looking for a specific wavelength of radiation emitted by singly ionized carbon atoms, may find more distant quasars. Ultraviolet light from quasars prompts surrounding gas clouds to produce such radiation, which is emitted in the far-infrared but redshifted to millimeter wavelengths. Detecting this light from the far reaches of the cosmos may indicate whether quasars and massive black holes existed before galaxies did, Loeb says.

– R. Cowen

Floods flow from small climatic shifts

Day after day, currents of carbon dioxide and other greenhouse gases waft over the planet, threatening to bring about potentially disastrous shifts in the global climate. Given a shifting climate, what sorts of changes will people actually experience?

Geologist James C. Knox of the University of Wisconsin-Madison has probed the geologic record of past floods to provide one answer. And in the Feb. 4 NATURE, Knox reports that relatively modest shifts in the globe's average annual temperature and precipitation may have dramatic regional effects on the frequency of catastrophic floods. The new study is one of a handful that link climatic change directly to local flooding, Knox says.

Computer simulations of global climate change emphasize long-term, gradual trends. However, "we should not assume that things will always be gradual," Knox points out. "The stratigraphic record shows many examples where things have changed rather quickly and abruptly."

Knox probed the sedimentary records of 68 floods along tributaries of the Mississippi River. During the past 7,000 years, he discovered, the largest floods carried 3-foot-wide boulders in their torrents and covered surrounding floodplains with over 16 feet of water.

However, Knox emphasizes the large effect that relatively minor climatic change can have on flood size. After the shift to a cooler, wetter climate some 3,300 years ago, the largest floods in the upper Midwest – equivalent to those now seen about every 500 years – occurred more frequently.

The changes in precipitation and temperature that apparently brought on these floods are significantly less dramatic than those predicted for the future by global climate models. Based on indirect fossil evidence, Knox determined that the increase in flood size came with temperature shifts of 1°C to 2°C. In contrast, some models of global change predict future temperature increases of 4°C to 5°C.

Geologist Victor R. Baker of the University of Arizona in Tucson has also conducted research on ancient floods. These historical studies, he notes, show nature in action, whereas today's sophisticated, yet theoretical, global climate models show how we *think* nature works. Thus, Knox' findings are valuable because "they provide a complement – that is, they fill in what the other studies leave out." *– D. Pendick*

Counting photons in a cleaned-up crystal

Expressing data – whether scientific measurements or the sounds of a symphony orchestra – as strings of ones and zeros has proved a remarkably versatile means of handling and conveying information. Such digital information can be readily encoded as electrical signals or light pulses.

It's possible to conceive of using the presence or absence of a single electron or photon to represent a bit – either 1 or 0. But quantum effects limit the efficacy of such a strategy, even when the pulses contain more than one electron or photon. For example, because of quantum effects, laser-generated light pulses typically display random fluctuations in the number of photons present in each pulse (SN: 5/30/92, p.356).

Now, theorist Gershon Kurizki of the Weizmann Institute of Science in Rehovot, Israel, and his collaborators have proposed a scheme that could lead to precise control of the number of photons in light pulses. By reducing the energy required to extract a given pulse from a noisy background, such a technique represents a potential means of transmitting digital information more efficiently than at present.

The researchers describe one version

of their scheme in the February JOURNAL OF THE OPTICAL SOCIETY OF AMERICA B.

To circumvent the intrinsic noisiness of optical devices, Kurizki and his coworkers take advantage of strong interactions between an electromagnetic field and a stream of atoms passing through a special, porous structure fabricated from an electrical insulator. Known as a photonic crystal, this kind of structure prevents atoms embedded within it from spontaneously absorbing and reemitting light at wavelengths that fall within a certain range, creating a band gap (SN: 11/2/91, p.277).

The researchers suggest that by introducing a defect that disrupts the structure's orderliness in just the right way, they can use the defect to trap photons of a particular wavelength. The number of trapped photons initially present varies because of random fluctuations in the intensity of the laser light bathing the crystal.

But the uncertainty in the number of photons present can be removed by sending a beam of excited atoms, one by one, through the region of the defect. Alternately emitting and reabsorbing photons during their passage through such a structure, the atoms interact strongly with and modify the electromagnetic field associated with the defect-trapped photons.

Such interactions rapidly convert the electromagnetic field within the photonic crystal into a so-called photon-number state, meaning that a fixed number of photons is stored at the defect. In other words, the atomic beam acts as a kind of cleaning agent.

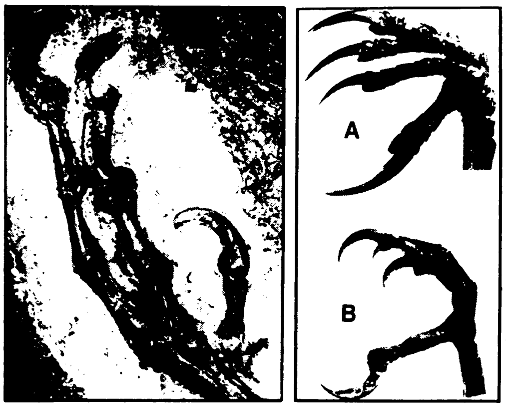
"The atoms remove the undesirable parts of the information, which is stored in the field," Kurizki says. "The remaining information within the field then conforms to what we would like to have."

The researchers can ascertain the existence of a particular photon-number state by looking for sequences in which each atom emerges from its interaction in an excited state. "One of the advantages of [our] strategy is that we can not only generate a photon-number state but also know in advance and adjust the conditions to get the right number of photons," Kurizki says. By establishing a well-defined photon-number state in a photonic crystal, researchers can exploit the ensuing certainty in the number of photons present for possible application in signal processing or optical computing.

However, no one has yet confirmed experimentally that it's possible to create a photon number state. Even the design of materials with photonic band gaps remains rudimentary (SN: 3/28/92, p.206).

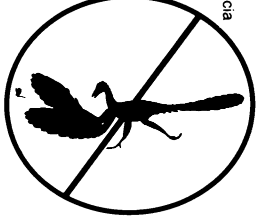
"From a technological point of view, this is still in its infancy," Kurizki says. "But these photon-number states are becoming a real possibility, and I think we are bound to see them within a relatively short time." *— I. Peterson*

Flight: A bird hand is worthy in the bush



Feduccia/SCIENCE

Archaeopteryx' curved foot claws (left) most closely match those of a perching bird, such as the bowerbird claw (top right, B). The predominantly ground-dwelling lyrebird has straighter claws (top right, A). Feduccia's cartoon (right) rejects the idea of Archaeopteryx *running after insects.*



Feduccia

By examining the claws on the most famous fossil animal, an ornithologist has scratched open an old and bloody debate over how birds developed the ability to propel themselves through the skies.

Most paleontologists in recent years have backed the theory that birds evolved from feathered dinosaurs that ran along the ground jumping after insects. But the new work suggests that the earliest known bird had claws designed to perch in trees, countering the "ground-up" theory for the origin of flight, says Alan Feduccia, who reported his work in the Feb. 5 SCIENCE.

The ancient bird at the center of this debate is *Archaeopteryx*, a crow-size creature that lived 150 million years ago and is the oldest known bird. Paleontologists discovered the first *Archaeopteryx* fossil in 1861 and have since unearthed five other specimens. All come from a particular site in southern Germany, where they were preserved in exquisite detail by a fine-grained limestone prized for its use in lithography.

Archaeopteryx has captivated succeeding generations of scientists because the specimens show feathers and other structures not normally preserved in fossils.

Feduccia, an ornithologist at the University of North Carolina at Chapel Hill, began his study by analyzing the claw geometry of nearly 300 modern birds from 30 different species. He found that the degree of claw curvature is a clear indicator of lifestyle: Ground-dwelling species have straighter claws, perching birds have moderately curved claws, and birds that climb tree trunks have very curved claws. Almost all modern birds have claws only on their feet.

Comparing *Archaeopteryx'* claws to the modern examples, Feduccia found that the oldest bird did not fit into the ground-dwelling group. Instead, the foot claws of *Archaeopteryx* most closely resemble those of perching birds, while the hand claws of *Archaeopteryx* matched the foot claws of tree-climbing birds.

"I think the evidence is overwhelming that *Archaeopteryx* was an arboreal [tree-dwelling], flying bird. And once you show that, there is a crack in the dam of the entire ground-up theory of avian origins," Feduccia says.

The new work will surely rekindle the smoldering conflict over the origins of birds and flight. Feduccia and many other ornithologists subscribe to the long-standing theory that birds evolved from primitive tree-dwelling reptiles that used feathered limbs to break their fall while leaping from branch to branch.

Many paleontologists, however, support a theory championed 20 years ago by paleontologist John H. Ostrom of Yale University. Ostrom, who identified a previously unrecognized specimen of *Archaeopteryx*, proposed that the early bird had legs, feet, and claws best suited for running along the ground rather than perching. He also observed that *Archaeopteryx* shared substantial anatomical similarities with the small bipedal dinosaurs that lived at the same time during the late Jurassic period.

Putting the two observations together, Ostrom proposed that birds evolved from small theropod dinosaurs that had evolved feathers. Although first used for insulation and for display, the feathers could have gradually helped these running bipeds jump and trap insects.

As paleontologists have solidified the link between birds and theropods, the dinosaurian origin theory has come to dominate its competitor in the scientific journals. Meanwhile, the two opposing camps have entrenched their positions, and the argument has turned personal, with researchers attacking one another in newspaper and magazine articles.

Avoiding the vitriol, Ostrom praises Feduccia's study even though it disproves Ostrom's contention that *Archaeopteryx'* claws were poorly designed for perching. "I think Alan has put together a very solidly based study. I'm not set in concrete," says Ostrom. While he grants that *Archaeopteryx* could probably perch in trees, Ostrom maintains that the bulk of the anatomical evidence indicates *Archaeopteryx* could run well and had evolved from running animals.

— R. Monastersky