ASTROPHYSICS

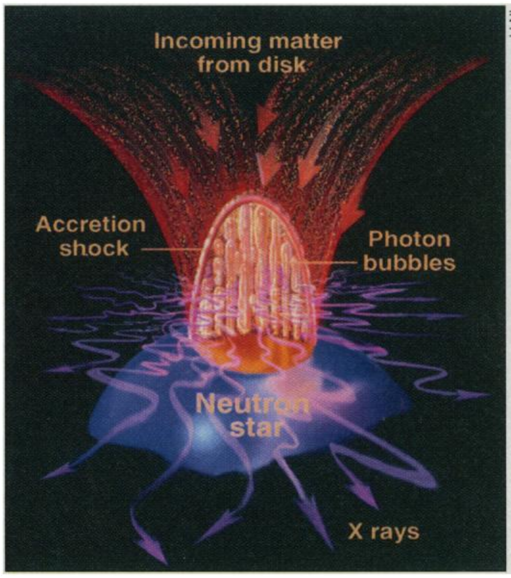
Photon Bubbles Put X-ray Fizz Into Neutron Stars

Above the atmosphere, most stars are fairly constant beacons, but star-sized x-ray sources pulse, oscillate, and flash. Theorists thought they were starting to understand why, but results from a new satellite are stressing their traditional explanations to the breaking point. Launched by NASA last December, the Rossi X-ray Timing Explorer (XTE) has instruments fast and sensitive enough to analyze in detail the fastest, faintest oscillations, and their complexity is putting theorists in a spin. It is also opening the door to a new theory that says the x-ray rhythms are really the sound of bubbles: bubbles of x-rays bursting near the surface of a neutron star.

Astrophysicists already knew that the oscillations had to originate in the source of the x-rays: superheated matter falling to the surface of a neutron star. They ascribed the signals to everything from vibrating shock waves to lumps in the matter. But detailed analysis of data from Rossi XTE, presented late last month at a San Diego meeting of the American Astronomical Society's high-energy astrophysics division, paints a different picture. Following intensive computer modeling, a team of researchers from the University of California, Berkeley, and the Lawrence Livermore National Laboratory proposed that the infalling streams of matter contain elongated "bubbles" of x-ray photons, and these bubbles are themselves vibrating to produce the observed oscillations. Although still far from proven and not without competitors, the proposal is "very exciting and tantalizing," says Charles Dermer of the Naval Research Laboratory in Washington, D.C.

X-rays are blocked by Earth's atmosphere, so this arm of astronomy did not really take off until the first x-ray satellites were launched in the 1970s. As a result, x-ray astronomy is still full of mysteries. Among them are the stellar x-ray sources, in which a neutron star sucks material from a nearby red-giant companion into a whirling "accretion disk." Close to the neutron star, its intense magnetic field funnels material from the accretion disk toward its poles, where columns of matter crash onto the surface, generating huge amounts of radiation. As the photons diffuse up the columns of infalling matter, says Jonathan Arons, one of the Berkeley team members, "[the matter] goes ka-blam on them and kicks them up to higher energy." This collision boosts the photons to x-ray energies, and they eventually diffuse out of the column into space.

Many x-ray sources—x-ray pulsars—deliver their photons to Earth in regular pulses, because the neutron star and its accretion columns are spinning rapidly, so the escaping photons are not always spraying out in our direction. This picture does not, however, explain the faster oscillations within each pulse that some x-ray satellites have detected. Based on the limited data available prior to Rossi XTE, some theorists believed that a conical "radiation shock wave," formed where the descending matter slams into outgoing radiation near the surface, oscillates up and down, modulating the x-ray output. Another model suggested that clumps of matter may form in the accretion disk and give rise to the oscillations as the clumps fall into the neutron star.



Naturally sparkling. Bubbles of x-rays may form in the matter crashing onto the magnetic poles of a neutron star.

These scenarios, however, may not be up to the task of explaining new observations from Rossi XTE presented at the San Diego meeting. Unlike its predecessors, XTE—"an amazing new probe," says Dermer—was specifically designed to take sensitive measurements of rapidly changing x-ray signals, which might hold clues to the detailed working of x-ray sources. Will Zhang of NASA's Goddard Space Flight Center in Greenbelt, Maryland, and Edward Morgan of the Massachusetts Institute of Technology, working with Arons and his colleagues Garrett Jernigan and Richard Klein, used that sensitivity to look at the recently discovered galactic x-ray source GRO 1744. Beneath this pulsar's beat of about two pulses per second, they found faster oscillations that have a noticeable peak at about 40 hertz and stretch out, with decreasing intensity, to about a kilohertz. In a separate announcement, a team led by Michiel van der Klis of the University of Amsterdam found oscillations at 1100 and 800 hertz in the bright, nonpulsar extragalactic x-ray source Scorpius X-1.

In an effort to explain these observations, Klein, Arons, and Jernigan began experimenting with a computer model of an accretion column they had recently developed along with Juliana Hsu of Livermore. The model took account of "every piece of physics imaginable," says Klein, including three-dimensional coupling between the intense radiation and the fluidlike flow of plasma within the strongly magnetized column. Although the model had to be run on a supercomputer, its physics is relatively simple: The radiation trying to fight its way up through the accretion column travels most easily through tenuous parts of the plasma—the path of least resistance. Hence any low-density areas tend to draw in radiation, which in turn pushes out more matter and clears the way for more photons. The result is elongated bubbles of photons stretching up the accretion column. As the bubbles grow longer, they begin to oscillate at characteristic frequencies, like the air in a bagpipe. "The radiation has to travel through a porous material," says Klein. "It gets out, but with a jitter or fluctuations."

The oscillation frequencies predicted by the supercomputer simulation fall in roughly the right range to explain the discrete oscillations in the sources studied by the Berkeley and Amsterdam groups. The model also predicts the continuous spectrum of oscillations at high frequency that Klein's team observed in their source. Klein predicts that van der Klis will find a similar spectrum if he examines the very high frequencies from Scorpius X-1 more closely. Van der Klis says it is too early to say if Klein is right: "I just heard his talk this morning."

The calculations still cannot account for certain features of the emission, such as the slight dependence of the oscillation frequencies on day-to-day changes in a source's overall brightness. As a result, some researchers say it's too soon to write off earlier theories. "I think everybody believes the [bubble] calculation itself," says Jean Swank of Goddard, project scientist of Rossi XTE. "Whether that's what we see in the data—I don't think we've unraveled that yet. It's going to be interesting to see which [explanation] wins."

–James Glanz