by Robert I. Hynes and Sheila J. Kannappan

Feeling Hot, Hot, Hot: The Universe in X-rays

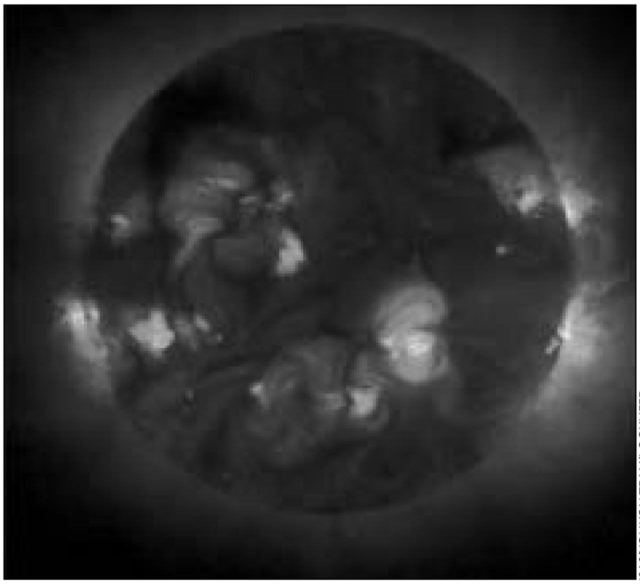
When we think of X-rays we often think of hospitals or airport security machines. X-rays are like magic, letting us see through solid objects. But X-rays are really just a super-energetic form of light. They consist of particles called photons just like visible light does, but an X-ray photon has more than a thousand times as much energy as a visible photon. We all know that when objects get hot they glow, in colors ranging from the red of a glowing ember to the yellow of a flame to the blue-white of a welder's torch. The Sun mostly glows yellow. However, above its surface lies a tenuous layer of gas so hot (over a million degrees) that it glows in X-rays. This layer, called the corona, is normally visible only when the Sun's bright surface is covered during an eclipse. But viewed in X-rays, the Sun's corona is the brightest thing in the sky.

Although we think of X-rays as able to pass through anything, this is not really true. The Earth's atmosphere acts like a filter, allowing visible light to pass but blocking X-rays. This makes X-ray astronomy much more challenging than optical astronomy.

The earliest studies used high altitude balloons and rockets. Today X-rays are studied from space with dedicated satellite observatories. In the earliest days of X-ray astronomy, nobody knew quite what to expect. The idea of X-rays coming from beyond the solar system was considered so speculative that early X-ray missions' primary goal was to detect X-rays from the Moon!

Instead, these missions found X-rays coming from far beyond the solar system, and the quest to understand their origin has taken us to some of the most extreme environments in the universe. The first X-ray source to be discovered, Scorpius X-1 in 1962, turned out to be a binary star system called an "X-ray binary." One of the stars is a normal star, but the other is a neutron star, the remnant of a prehistoric supernova. Neutron stars are incredibly dense, containing as much material as the Sun packed into a volume smaller than a city. The neutron star pulls the outer layers of the normal star toward itself, into an orbiting whirlpool of gas. As gas clouds swirl inward they accelerate, collide, and rub against each other, becoming so hot that they glow in X-rays as they fall onto the neutron star, which also glows in X-rays. In recent decades, many systems like Scorpius X-1 have been discovered in our galaxy and in other galaxies.

Some X-ray sources are even more exotic, powered by massive black holes. Black holes are even more dense than neutron stars, with gravity so intense that even light cannot escape once it passes the black hole "surface," or event horizon. Although black holes are themselves invisible, the hot gas plummeting toward their event horizons can be detected by vigilant X-ray astronomers. Some black holes are supernova remnants only slightly more massive than neutron stars. Others are enormous, up to a billion times more massive than the Sun. These giants live in the centers of galaxies such as our own. Gas falling into them can produce intense visible and X-ray light, sometimes creating brilliant galaxy nuclei that outshine even their galaxy hosts. Stars that approach too close are torn apart, leaving clues that may explain the mysterious X-ray flares seen in the centers of some galaxies.



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An X-ray view of the Sun reveals churning activity in its outer layer, the corona.

Recently the Chandra X-ray Observatory's high-resolution X-ray pictures have brought attention to another mysterious class of objects in nearby galaxies, "Ultraluminous X-ray Sources," or ULXs. Brighter than ordinary X-ray binaries, but fainter than the bright cores of active galaxies, ULXs may be energized by an intermediate-mass class of black holes. These midsize black holes may form the building blocks of giant black holes and resolve the long-standing mystery of how such giants form. Alternatively, ULXs may be massive X-ray binaries found in temporary ultra-luminous states, or states that produce narrow, intense X-ray beams, which sometimes point toward us by chance. Many astronomers now suspect that both explanations could be true and that ULXs may actually represent two or more different kinds of object, further adding to the X-ray zoo.

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