vivo analysis of neuronal activity with genetics is what makes the zebrafish a powerful model system for studying vertebrate neurobiology. This is exemplified by the work of Patrick Page-McCaw (Herwig Baier's lab, University of California, San Francisco), who has devised a way to screen zebrafish for learning abnormalities. When exposed to a series of taps, zebrafish larvae eventually learn not to be startled. They are not simply tired and therefore unable to respond, as a mild electric shock startles them even when they are oblivious to taps. Physiological analysis, combined with positional cloning of mutants isolated in this learning screen, should provide new insights into the neural processes controlling learning in vertebrates.

The zebrafish field is clearly maturing. A sentiment from the previous meeting—"How exciting! So many new genes!"—was not heard at this meeting. Perhaps the deluge of data from the expressed sequence tag and genome-sequencing projects has quenched our thirst for assigning new names to specific bits of genetic code. With the positional cloning of so many mutants already complete, labs are now turning their efforts to understanding the molecular pathways that are disrupted in these mutants. In vitro assays for ubiquitination, growth cone turning, and microscopy of green fluorescent fusion proteins are just some of the methods being avidly adopted to study zebrafish physiology and cell biology.

But when will the zebrafish contribute to a major breakthrough in understanding vertebrate biology, or even to the discovery of a fundamentally new phenomenon? This question came up in a discussion of the new edition of *Molecular Biology of the Cell*, which barely featured the zebrafish. For all the enthusiasm in the field, so much knowledge of cell and developmental biology has already been learned from other organisms that it is not clear what this fish can tell us. Now is the time for newcomers to the field to think hard about major questions that the zebrafish is uniquely suited to answer. For example, questions about development and function of the vertebrate brain or disease susceptibility that can best be answered through a combination of genetics and in vivo analysis for which the zebrafish is ideal. Hopefully, the enthusiasm and cooperative spirit of the fish community, combined with the tools and resources already available, will soon translate into exciting discoveries. Organizers of the next meeting might do well to remove the "development" tag from the title, because the zebrafish has become a model for much more. Perhaps we shall all be surprised by what the zebrafish will reveal about vertebrate biology to those with receptive minds asking the right questions.

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PERSPECTIVES: ASTRONOMY

X-ray Astronomy—40 Years on

Herbert Gursky

On 18 June 1962, the rocket that first detected cosmic x-rays was launched from the White Sands Missile Range in New Mexico (*1*). Today, cosmic x-ray emission, a signature of hot plasmas and relativistic electrons, is known to be ubiquitous in nature, especially from neutron stars and black holes.

The team responsible for the 1962 launch—Riccardo Giacconi, Frank Paolini, and I—then worked for American Science & Engineering (AS&E), a company now best known for airport x-ray inspection machines. The suggestion to study cosmic x-ray emission had come from Bruno Rossi, a professor at MIT and the chairman of AS&E's board of directors. As a member of NASA's Space Science Board, he was familiar with discussions relating to the potential of x-ray observations.

AS&E's principal business at that time was to measure the effects of nuclear weapons, mostly relating to x-rays. In June 1962, almost the whole technical staff, including Giacconi and Paolini, were in the Pacific, preparing for the Starfish high-altitude nuclear test that took place a month later.

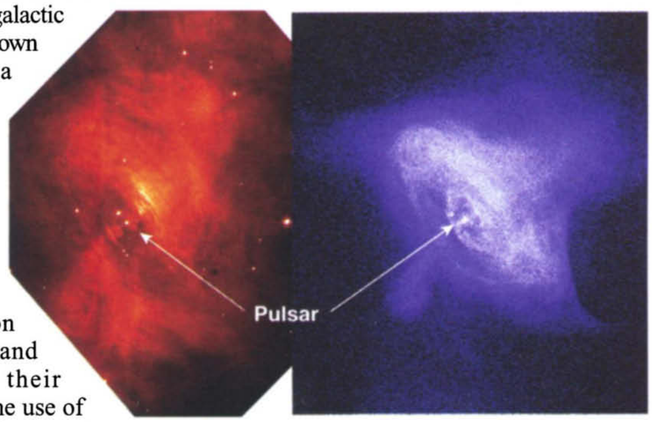
The Moon was the principal target of the June 1962 rocket flight. After calculating its emission based on fluorescence of its surface by incident solar x-rays, we decided that it could be detectable, if barely, during a rocket flight. The data revealed a very strong peak of radiation in the south. But it could not be the Moon: It was much too strong and did not line up with the Moon's direction as seen in an optical photometer.

I initially thought the radiation might be the result of local, energetic electrons. But after a few weeks of analysis, we concluded that the most likely source of the observed radiation was from outside the solar system and that the strong peak was from the general direction of the galactic center. The peak is now known to be caused by Sco X-1, a faint object in the constellation of Scorpius.

The results were certainly a surprise, but not an accident. In 1962, AS&E already had an active research program devoted to the study of x-ray radiation from space. Giacconi and Rossi had published their landmark paper (*2*) on the use of grazing incidence reflectors to study cosmic x-rays and had cited the Crab Nebula as a potential source. Two other groups were developing rocket instruments for studying cosmic x-ray emission: Herbert Friedman's group at the Naval Research Laboratory and a group headed by Phillip Fisher at Lockheed Missiles and Space Company. Albert Baez had even organized a conference on the subject of observing cosmic x-rays.

At the time, no one had a good reason to expect strong x-ray sources. But considering the advances taking place in radio astronomy, everyone expected this new window into the universe to yield its share of discoveries.

Within a few years, Sco X-1 and Cygnus X-2 were identified with faint blue stellar objects. This observation led to the idea that the x-ray emission originated from accretion from a normal star onto an unseen compact companion, such as a



The interior of the Crab Nebula. (**Left panel**) Visible light image of the Crab Nebula obtained with the Hubble Space Telescope taken in March 1994 at about 550 nm (green). (**Right panel**) Chandra x-ray image of the same region taken in August 1999 at about 3 KeV. The images are about 2 light years across.

CREDIT: NASA

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white dwarf or a neutron star. The radio pulsar in the Crab Nebula was also found to be a powerful x-ray source.

The 1960s were the great decade of astronomy. Radio pulsars and astronomical x-rays were discovered; the radio stars discovered in the late 1950s were found to be high-redshift quasars; the microwave background radiation was discovered and correctly identified as the relic radiation of the big bang; and the foundations for gravitational wave and neutrino astronomy were laid.

The decade ended with the launch of Uhuru, a space mission dedicated to x-ray astronomy that used the detector technology developed for sounding rockets. Uhuru soon provided evidence for the subsecond variability of Cygnus X-1. On the basis of this discovery, along with the detection of its optical counterpart as a binary system with a massive, invisible companion, Cygnus X-1 became a credible candidate for a black hole. By now, a dozen such objects believed to be black holes have been found in the Milky Way.

In addition, UHURU data revealed that other x-ray sources, notably Cen X-3 and Her X-1, pulsed periodically with the same range of periods found for radio pulsars. Cyclic variations in pulse periods revealed that these objects were members of close binary systems. Pulsating x-ray sources and radio pulsars are neutron stars in different settings. The x-ray sources are in binary systems and are powered by accretion from the normal star onto the neutron star. Radio pulsars are mostly single objects that draw their power from their magnetic field and their rotation.

Today, x-ray observations are part of the arsenal of techniques used to survey the universe. The Chandra Observatory and XMM Newton, along with several other x-ray space missions, have produced imagery and spectroscopy comparable to what is obtained at other wavelengths. X-ray astronomy has virtually disappeared as a distinct discipline as observers move effortlessly from one wavelength range to the next.

The Crab Nebula provides an example of how x-ray astronomy, and astronomy more generally, has been transformed. The Crab remains one of the great laboratories for studying relativistic astrophysics. Since its discovery, it has been understood that the Crab pulsar is the engine generating the relativistic electrons that are revealed as synchrotron radiation extending from radio to ultrahigh-energy gamma rays.

The value of x-ray images can be seen by comparing a visible-light Hubble Space Telescope image (*3*) of the interior of the Crab Nebula with an x-ray Chandra image (*4*) (see the figure). The x-ray image, while not nearly at the resolution of the visible image, clearly reveals the essential features of the central engine: The pulsar itself sits at the center of equatorial bands of radiation, with a jet along the equatorial axis. These features are also present in the Hubble image in even greater detail, but one has to know that they are there because the background of visible light from elsewhere in the nebula confuses the interpretation.

These x-ray observations of the Crab and others like it yield insights not only into pulsars but also into binary x-ray sources and quasars. They begin to resolve one of the last frontiers of astronomy: the nature of phenomena in the vicinity of neutron stars and black holes.

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PERSPECTIVES: SPACE SCIENCE

How to Cope with Space Weather

Daniel N. Baker

Charles Dudley Warner once famously remarked that "everybody talks about the weather but nobody does anything about it." Space weather is the latest topic of conversation, but scientists are doing more than just talk about it.

Above the troposphere—the thin atmospheric layer above Earth's surface in which normal weather occurs—lies a vast region extending into interplanetary space that is permeated by highly fluctuating magnetic fields and very energetic particles. These collective, often violent, changes in the space environment around Earth are referred to as "space weather." With observations, numerical simulations, and predictive models, scientists are now making progress toward dealing with space weather (*1, 2*).

The source of space weather is the Sun, which regularly emits giant clouds of ionized gas containing 10^{16} g or more of hot plasma (see the second figure, top panel). These clouds, called coronal mass ejections, move away from the Sun at speeds of 1000 km/s or more, carrying with them strong magnetic fields and highly energetic particles. The Sun also emits powerful solar flares and streams of high-speed solar wind flows.

Aurora borealis. This image was taken at Nome, Alaska, on 28 November 2000. For more images see http://northernlightsnome.homestead.com.

CREDIT: JOHN RUSSELL/NOME, ALASKA

As these solar emissions reach Earth and its vicinity, they can give rise to long-lasting disturbances called geomagnetic storms. The aurora borealis, visible at high latitudes, is the most widely known manifestation of these storms (see the first figure). They can also cause substantial damage to Earth-orbiting spacecraft and to humans in space (*3*) and severely disturb electric power or communications systems.

When high-energy protons and other ions hit orbiting spacecraft, they can leave ionization tracks in microminiaturized electronics (see the second figure, bottom panel). These tracks can upset spacecraft computer memories and otherwise disrupt sensitive space electronics. As a result, satellite solar power panels may be damaged, optical tracker systems may become confused, and spacecraft command-and-control software may be scrambled. High-energy protons and ions may also hurt, and potentially kill, astronauts who are in space during a major solar particle event (*4*).

Very energetic (relativistic) electrons in the space environment can also be devastating to spacecraft. They can readily penetrate even thick spacecraft shielding and bury themselves in insulating materials, such as coaxial cables or electronics boards, deep within spacecraft systems and subsystems (see the second figure, bottom panel). As charge builds up in the insulting materials, a powerful internal electrical discharge can occur (*2, 3*), much like a miniature lightning strike. Numerous recent spacecraft failures have been attributed to this mechanism (*2, 3, 5*).

Another space weather effect is known as "surface charging" (see the second figure, part C of bottom panel). Lower energy (10 to 100 kV) electrons cannot penetrate

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