Infrared astronomy experienced a boom during this time, thanks to Nancy Boggess of NASA, and we owe her credit for four major projects: the Infrared Astronomical Observatory, COBE, the Spitzer Space Telescope, and the Stratospheric Observatory for Infrared Astronomy (SOFIA). To make a long story (*2*, *3*) short, the COBE spacecraft was launched in 1989, proved that the background radiation has a blackbody spectrum within 50 parts per million (ppm) and is therefore the remnant of the hot Big Bang, that it has anisotropies at 10 ppm presumably due to the quantum mechanics of the Big Bang, and that there is a cosmic infrared background radiation field twice as bright as expected. The COBE project opened the field of precision cosmology, which now offers new questions like: What is dark matter? What is dark energy? Was the evolution of the universe after the Big Bang simple or complex? The details may be detectable through their influence on the polarization of the background radiation, but the questions about dark matter and dark energy require different approaches (*4*).

After COBE, I worried that NASA might never again do anything so exciting, but in October 1995 Edward Weiler at NASA Headquarters asked me to work on the Next Generation Space Telescope, to follow the Hubble Space Telescope. This project is now named the James Webb Space Telescope (JWST), after the second NASA administrator, who persuaded Kennedy to start the Apollo program, and built up space science capabilities within NASA and universities. The JWST has reached technological maturity and is on its way to launch in 2013 (see the figure). The telescope will carry out infrared observations, from 0.6 to 29 µm, that even the mighty Hubble could not undertake. Most of this wavelength range cannot be observed from the ground, and the JWST will be far more sensitive than the Hubble and Spitzer telescopes that preceded it. The European Space Agency and Canadian Space Agency are contributing major components (*5*).

With the JWST, future observers might study the first objects to form after the Big Bang, the formation of galaxies like the Milky Way, the formation of stars and planets, and the development of planetary systems capable of supporting life. The JWST is built with unclassified technology, but without the national investment in detectors and space optics for military and surveillance purposes, the JWST could not be built. Swords are sometimes beaten into plowshares.

What does the future hold for science, and the world? One doesn't have to be a rocket scientist to know that science, engineering, and management are all required for the challenges of energy supply, environmental quality, and public health. Management of catastrophic events, from bridge collapse to wars, from volcanoes and earthquakes to tsunamis, storms, droughts, plagues, and killer rocks from the sky, is not out of range of human capability. If we can put a man on the Moon, why can't we do these other things? Technologically, we can, of course. Although there is no simple process for achieving worldwide consensus and taking worldwide action, nothing concentrates the mind like clear and impending doom. Perhaps climate change and energy supply will be the Sputnik for the next generation.

As to the long-term outcome, I'm cautiously optimistic. Kennedy challenged the United States to go to the Moon, not because it was easy, but because it was hard, and the nation responded. NASA's mission continues to expand the human sphere, both by observation and by travel, and I can imagine no discovery more fundamental than life on other planets, here in the solar system, or around some other star.

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HISTORY OF SCIENCE

Sputnik and Satellite Astronomy

Giovanni F. Bignami

After Sputnik, European researchers emphasized basic research over politics and made important discoveries in space-based astronomy.

Few sounds have turned out to be more international than the "bip…bip" of the Sputnik satellite (*1*). Sputnik didn't speak Russian or English when it was launched in October 1957, yet it was clearly understandable and immediately popular. However, from the prestigious radio telescope at Jodrell Bank in the United Kingdom to amateur radio buffs in Turin, Italy, Sputnik's signals were regarded, at least in Europe, as a tribute more to science than to politics.

A generation of leading European physicists at the time, including Henk van de Hulst in the Netherlands, Giuseppe "Beppo" Occhialini in Italy, and Reimar Lust in Germany, immediately understood the science potential of space. Occhialini, for example, teamed up with an illustrious immigrant to the United States, Bruno Rossi, to start a space research program in Italy and Europe, the European Space Research Organization (ESRO), which later became the European Space Agency (ESA). Before Sputnik, the European school of physics had already been thinking about a unified particle physics laboratory (soon to become CERN) and now they turned their attention to space.

The author is at the Istituto Universitario di Studi Superiori, 27100 Pavia, Italy. E-mail: gfb@lambrate.inaf.it

NASA was coming together in the United States at about the same time. There was, however, a fundamental difference. NASA had been created from the start to counter not only Sputnik but also Laika the dog (1957) and Gagarin the man (1961). Europe was not under the same kind of pressure and could afford the luxury of creating ESRO in 1962, entirely dedicated to science. The European space science program lives on today as the sole mandatory part of ESA (created in 1975) and is a direct legacy of the reaction to Sputnik of those physicist "founding fathers."

When space astronomy started in the 1960s, the first goal was to search for high-energy photons invisible on the ground because they were being absorbed by our atmosphere. These x-rays carry information about truly fundamental processes in celestial objects, including the life and death cycles of stars. Enrico Fermi's Italian school of physics deserves credit for helping invent the technology for building telescopes to gather high-energy photons in space. Three graduates of this school, Rossi at MIT, and Giuseppe Vaiana and Riccardo Giacconi at Harvard, led groups that conceived and constructed x-ray detectors and telescopes later flown in space by NASA.

Astronomy with x-rays thus joined radio

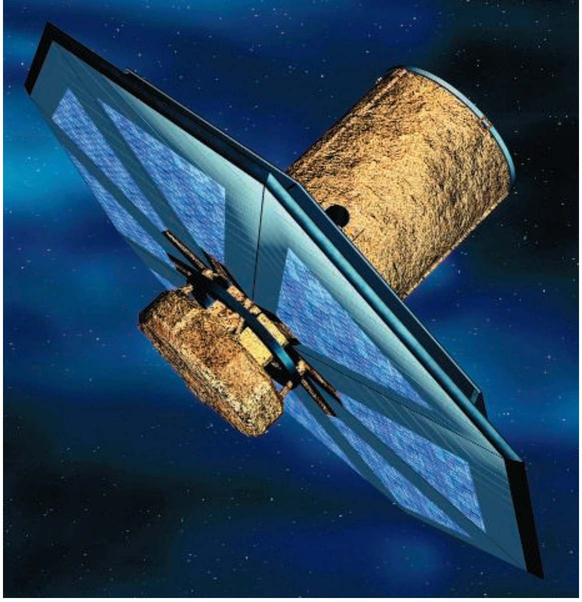
astronomy and moved us into an era of observing the invisible. Out of proportion with its modest budget, ESA's many missions have contributed to discoveries that poured in over the decades as detectors covering the full wavelength spectrum were launched from different continents. X-rays, for example, helped us understand the mechanisms of the solar corona. Stars, young and old, sometimes shine much brighter in x-rays than in the optical spectrum, and x-ray detectors provided a new look at their evolution and death. X-rays have shown us how stars collapse when they die and leave behind cores of a new state of matter, such as neutron stars. More important, x-rays from space gave the first evidence for black holes, objects so dense that not even light can escape them. Giacconi shared a Nobel prize for physics in 2002 for these and other discoveries.

Gamma-ray astronomy, another science of the invisible, has shown us objects emitting radiation that, on Earth, is produced only by radioactivity and particle accelerators. ESA's first mission, COS-B (1975), for example, showed the reality of "gamma-ray stars," that is, neutron stars that are only visible in gamma-rays (*2*).

Gamma-rays were also the protagonists of a unique success story in space science. During the Cold War, gamma detectors were launched to ferret out covert nuclear tests. Sure enough, the Vela spy satellites (a "secret" code name from the Spanish "velar," to monitor) launched by the United States detected suspicious bursts of gamma-rays. However, they came from the sky and not from the USSR (*3*), as was first disclosed at a 1973 conference where Soviet scientists admitted observing something similar. Gamma-ray bursts represented one of the top astronomical enigmas for a quarter of a century until the Italian/Dutch satellite BeppoSax (*4*), launched 10 years ago, showed that the bursts originated from enormous explosions in galaxies at cosmological distances, when galaxies were being born into a young Universe.

No one had observed stars being born before the development of satellite-based infrared astronomy, which yielded the first images of star "nurseries." These are "warm" (by interstellar standards, actually –200°C) dust cocoons, collapsing to form tens of new baby stars. Space infrared telescopes, such as ESA's Infrared Space Observatory (*5*), have also shown that water is abundant wherever stars are conceived and, in general, that water is everywhere in the sky. Water, we have learned, is the second most abundant molecule, after hydrogen, in the Universe. Think of it when you go swimming: You are floating in molecules that had probably been around for some time before raining on the newly formed Earth.

Where should we look in the next half-century? Europe has set for itself a long-term "Cosmic Vision" (*6*) to carry space science to 2025. Alas, we have discovered, like everyone else has, that choosing is hard. We want to study gravitational waves and we want to understand dark energy; we want to travel to Mars and we want to explore Jupiter. We need large interferometric telescopes in space to discover new planets (see the figure) and we need large orbiting collectors to catch more photons. To make a "concord out of this discord" is the challenge being faced by the new generation of European researchers.



Other worlds. The proposed Darwin mission is a group of four satellites that will search for Earth-like planets and analyze their atmospheres for chemical signatures of life.

CREDIT: EUROPEAN SPACE AGENCY

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EVOLUTION

Feathers, Females, and Fathers

Sex linkage of genes involved in adaptation and speciation extends to birds, explaining why females prefer males of their own species.

Michael G. Ritchie

Alfred Wallace, Darwin's contemporary and rival, argued that when species hybridize, natural selection favors individuals who are more fussy about whom they mate with, which therefore increases female discrimination of males from different species (*1*). Modern evolutionary genetics has questioned the importance of the "Wallace effect" (also known as "reinforcement") because genetic recombination between female discrimination and male trait genes would scramble combinations of loci that favor speciation. Several solutions to this have been proposed, including close genetic linkage of such loci. A simpler possibility is sexual imprinting, which causes a female to prefer males that resemble her father. A study of flycatchers by Sæther *et al*. on page 95 of this issue (*2*) has taken advantage of natural hybridization that occurs between species of this bird, and demonstrates that female preference for father-like males is due to sex linkage of genes for female preferences rather than to sexual imprinting. The linkage of genes that influence speciation to sex chromosomes may turn out to be a common influence on the origin of species.

The evolutionary biologist J. Felsenstein (*3*) famously argued that because of genetic recombination, there might be fewer species of animals than we expect. In other words, if sexual species hybridize, recombination jumbles up their genes such that independent sets of loci coding for hybrid unfitness, male sexual traits, and female preferences are unlikely to crystallize out into new species. Exceptions may occur if the genes are all tightly genetically linked on one chromosome. Felsenstein also recognized that a "single-allele" solution could facilitate speciation. In this case, allelic replacement at one locus simultaneously causes selective mating between individuals

The author is at the University of St. Andrews, Fife KY16 9AJ, UK. E-mail: mgr@st-andrews.ac.uk