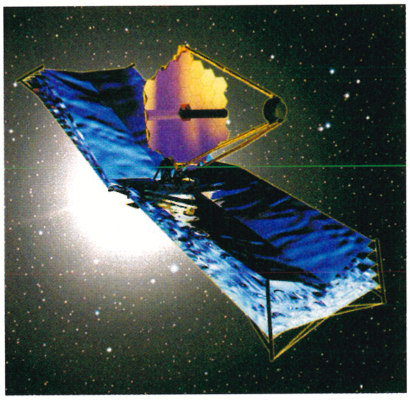
# Astronomers Envision New Observing Instruments in Next Decade to Focus on Farthest Reaches

Of all of today's scientists, astronomers seem best able to agree on the instruments they need for their far-out discoveries. Astronomers have excelled at this since the 1960s, when the National Research Council (NRC) of the National Academy of Sciences assembled a committee, led by Albert Whitford of the University of California, Santa Cruz, to survey the field and to develop a wish list of new research facilities for the ensuing decade. To the surprise of many other scientists, the Whitford panel not only came up with a coherent list of priorities but persuaded NASA, the National Science Foundation (NSF), and Congress to foot the bill for the instruments of choice. This activity has now been repeated with great success four more times—once each decade by a different panel and chairman. The latest decadal survey, bearing the title "Astronomy and Astrophysics in the New Millennium," was released as an unedited draft of 147 pages on 18 May. It is destined to be as successful as the previous ones.

What is it about astronomers that allows them to decide on their priorities with relative ease, whereas physicists, chemists, and other scientists are rarely able to reach agreement? Roger Blandford, a theoretical astrophysicist at Caltech, believes the answer lies within the nature of astronomy, which is principally an observational and taxonomical science. Astronomy progresses through information gathering and data analysis. Its instruments, such as telescopes and computers, are expected to advance the exploration of the cosmos and, as the technology improves, to be upgraded. It is therefore easier, Blandford claims, for astronomers to make decisions about meaningful instruments than to rely on experiments—as physicists, chemists, biologists, and other scientists do—before making decisions on the next generation of instruments. What's more, astronomy has fewer practitioners than almost any other science, so that the sociology of numbers applies, which makes it possible for astronomers to unite on important questions and facilities.

The truth is that the fundamental goal of astronomy and astrophysics for the 21st century hasn't changed from that of previous centuries: to develop a comprehensive understanding of the formation, evolution, and destiny of the universe and its constituent galaxies, stars, and planets. What's different today is that the boundaries and problems seem almost limitless. Astronomers study the universe and its constituents as these have evolved through cosmic time. More particularly, as the new NRC report states, astronomers seek to determine how stars and their planetary systems developed out of collapsing interstellar clouds in the galaxy; what are the shape and properties of the universe; how interstellar and intergalactic gas accumulate the elements created in stars and supernovae; and what is the mysterious dark matter (and possibly dark energy) that so strongly influence the large-scale structure and dynamics of the universe.



FIRST CHOICE: Next Generation Space Telescope shown here as TRW's concept.

"We must use the universe as a laboratory—a unique laboratory—for probing the laws of physics in regimes not accessible on Earth, such as the very early universe or near the event horizon of a black hole," the report says. "We must search for life beyond the Earth and, if it is found, determine its nature and its distribution. And finally, we must develop a conceptual framework that accounts for all that we have observed."

In issuing the 1991 astronomy survey, the committee's chairman at the time, John N. Bahcall of the Institute for Advanced Study in Princeton, New Jersey, correctly predicted that the 1990s would be an exciting decade of discovery and that "each new discovery would lead to new puzzles." That's exactly what happened.

The most challenging discoveries of the past decade included determining the interior structure of the Sun from observation of its seismic activity; discovering evidence suggesting both that the universe is "flat," as predicted in inflationary cosmologies, and that its expansion is accelerating due to the presence of "dark energy"; identifying massive black holes in the nuclei of galaxies, particularly in our own Milky Way; locating dozens of planets orbiting other stars; and finding "brown dwarfs," cool stars too small to sustain nuclear reactions in their interiors.

Astronomy carried out in space has produced spectacular images of the cosmos at wavelengths ranging from the far and near infrared, through optical and ultraviolet, to x rays. "Because 'a picture is worth a thousand words,' these beautiful and exotic images elicit an immediate and visceral response among scientists and nonscientists alike," the new report observes. "Their tremendous impact helps explain the public's enthusiasm for the nation's space program. The data provided by the suite of NASA missions has revolutionized our understanding of the universe."

Opportunities for ground-based astronomy are equally challenging and compelling, the report goes on to say. "For example, the Keck and Gemini telescopes offer high resolution spectroscopic capabilities that, combined with theoretical analysis and computational modeling, can yield insight into the dynamics, chemical composition, and evolutionary state of the objects imaged in space, as well as a wealth of other astronomical phenomena detected from the ground. In addition to very large filled apertures, another advantage that ground-based facilities have over their space-based counterparts is the short lead-time between the latest breakthroughs in the fast-moving electronics and related industries and the incorporation of such advances in sophisticated instrumentation at the back ends of telescopes. Large-scale optical, infrared,

## Priorities in Astronomy and Astrophysics in the New Millennium

| Ground-based | Cost (in millions of dollars) | Space-based | Cost (in millions of dollars) |
|---|---|---|---|
| Giant Segmented-MirrorTelescope (GSMT) | 350 | Next Generation Space Telescope (NGST) | 1000 |
| Expanded Very Large Array (EVLA) | 140 | Constellation-X Observatory | 800 |
| Large-Aperture Synoptic Survey Telescope (LSST) | 170 | Terrestrial Planet Finder (TPF) | 200 |
| | | Single-Aperture Far Infrared (SAFIR) Observatory | 100 |
| Telescope system instrumentation program | 50 | | |
| Advanced Solar Telescope | 60 | Gamma-ray Large Area Space Telescope (GLAST) | 300 |
| Square Kilometer Array technology development | 22 | Laser Interferometer Space Antenna (LISA) | 250 |
| Combined Array for Research in Millimeter-wave Astronomy (CARMA) | 11 | Solar Dynamics Observatory (SDO) | 300 |
| Very Energetic Radiation Imaging Telescope Array System (VERITAS) | 35 | Energetic X-ray Imaging Survey Telescope (EXIST) | 150 |
| Frequency Agile Solar Radiotelescope (FASR) | 26 | Advanced Radio Interferometry between Space and Earth (ARISE) | 350 |
| South Pole Submillimeter-Wave Telescope | 50 | | |
| National Virtual Observatory (NVO) | 15 | National Virtual Observatory (NVO) | 45 |
| Laboratory astrophysics program | 5 | Advanced Cosmic-ray Composition Experiment for Space Station (ACCESS) | 100 |
| Low-Frequency Array | 8 | Augmentation of astrophysics theory program | 30 |
| National theory postdoctoral program | 6 | Laboratory astrophysics program | 40 |
| Synoptic Optical Long-term Investigation of the Sun (SOLIS) expansion | 8 | National theory postdoctoral program | 14 |
| | | Ultra-long duration balloons | 35 |
| Total ground-based | 956 | Total space-based | 3714 |
| Total | 4670 | | |

and radio surveys and synoptic studies, requiring decades of precise measurements on a large number of targets, may also be done advantageously on the ground. Adding to the excitement, ground-based astronomy is moving beyond traditional boundaries of optical and radio disciplines into neutrino and gamma-ray astronomy as well."

Today, said Joseph Taylor, the Princeton University astrophysicist who was joint chairman of the survey committee, "conditions are ripe—as ripe as I can remember them at any time in my professional life—for very significant progress to be made to find out answers to particularly intriguing questions, using modern astronomical techniques. We need to sort out the many conflicting ideas. It is inevitable that deeper understandings of nature's most fundamental laws will be revealed as well, with who knows what important consequences for our civilization."

Organized in December 1998, the committee, consisting of 15 astronomers and astrophysicists, and nine subpanels, with 106 members, grappled with the problems and priorities of the field for nearly a year. The committee was chaired by Taylor, who shared a Nobel Prize in 1993 for finding evidence of gravitational waves from a binary pulsar, and Christopher McKee, a theoretical astrophysicist at the University of California, Berkeley. The panel's final draft was submitted to 23 NRC reviewers who then sent back 120 pages of critiques, which McKee often found "awesome." Final cost of the survey was nearly $2 million, put up by NASA, NSF, and the Keck Foundation.

The committee's estimated sticker price for the initiatives and facilities for the decade of 2000–2010 comes to $4.7 billion—nearly 20% more than the $4 billion price tag for the priorities recommended in the Bahcall report for the 1990s.

Leading the new millennium list is the Next Generation Space Telescope (NGST), which would orbit a million miles from Earth and use an 8 m deployable mirror to observe in the infrared, with hundreds of times the sensitivity of the Hubble Space Telescope, the oldest and faintest stars and galaxies. Lockheed Martin, TRW, and NASA are already engaged independently in developing technologies and designs for the observatory. European and Canadian space agencies have indicated they will make major contributions to the estimated $1 billion cost of constructing the NGST, which is projected for launch in 2009.

Second highest on the list is the ground-based 30 m Giant Segmented-Mirror Telescope (GSMT), similar in design to the existing Keck telescopes in Hawaii but three times their diameter. The proposed $350 million telescope would be "a powerful complement to the NGST in tracing the evolution of galaxies and the formation of stars and planets," the report asserts.

Just as the Keck telescopes complement Hubble's high-resolution images with high-resolution spectroscopy, the NGST and GSMT would provide astronomers with a powerful pair of optical-infrared observatories for addressing problems ranging from the evolution of galaxies to the search for planets around distant stars. Although several concepts have been considered recently for massive ground-based telescopes with apertures varying in size from 30 to 100 m, the survey committee chose the low end of the scale, preferring caution over capacity. "When we looked at the technology for a 100 m telescope, we got scared," said Taylor. It might have been possible to take part in the development of the 100 m Overwhelmingly Large (OWL) telescope, which is under study by the European Southern Observatory, but the Taylor–McKee committee recommended against it and urged US government agencies to share half of the GSMT's considerable cost with either international or university partners.

Other major initiatives, defined as space-based facilities costing more than $500 million and ground-based projects above $50 million, include, in order of priority, the Constellation–X Observatory, a suite of four powerful x-ray telescopes costing about $800 million, to replace the current Chandra X-ray Observatory and focus on the formation and evolution of black holes; an upgrade to the Very Large Array of radio telescopes in New Mexico; and the Large-Aperture Synoptic Survey Telescope (LSST), a 6.5 m wide-field, fast readout optical facility that would survey the entire visible sky down to faint objects at the 24th magnitude every week. Once known as the Dark Matter Telescope, the LSST was renamed to better reflect the variety of subjects it would study, from cataloging supernovae to finding 90% of all near-Earth asteroids larger than 300 m across.

At the lower end of the major projects, the committee listed the Terrestrial Planet Finder (TPF), a $200 million free-flying infrared interferometer that would be "a promising opportunity" for collaborating with the European Space Agency (ESA), which is considering a similar mission named Darwin. TPF, said McKee, would be "the most technically ambitious science mission NASA has ever attempted." Though ranked third among space-based missions, it is a personal favorite of NASA Administrator Dan Goldin.

The list of a dozen moderately sized instruments is topped by the $300 million Gamma-ray Large Area Space Telescope (GLAST), a joint NASA and Department of Energy (DOE) project with 30 times the sensitivity of the Compton Gamma Ray Observatory. (The Compton spacecraft was jettisoned in the Pacific Ocean early last month after one of its three gyros failed.) Another recommendation was the $250 million Laser Interferometer Space Antenna (LISA), a joint mission of NASA and the ESA, to pioneer the study of low-frequency gravitational waves from galactic binary star systems and the coalescence of supermassive black holes. A mission of this sort was recommended in the report of a physics survey panel last year to complement the ground-based Laser Interferometer Gravitational Wave Observatory (LIGO), an NSF project designed to track gravitational waves at much higher frequencies from the coalescence of neutron stars and stellar mass black holes, as well as from the core collapse of supernovae.

Smaller missions were not ranked, except for the first, a National Virtual Observatory to enable "a new mode of research" for astronomers seeking a one-stop shop for data as well as a potent public classroom.

The committee also calls for NASA, NSF, and DOE to place stronger emphasis on funding astrophysical theory, data archiving and mining, and laboratory astrophysics. More daunting is the panel's recommendation to reorganize the US optical astronomy community, now divided between observatories operated by private organizations, universities, or foundations and those that are government funded. The report proposes a new paradigm: "All facilities, whether nationally or independently operated, should be viewed as a single integrated system." Whereas the solar and radio astronomy communities cooperate, those in the optical community tend to operate on their own, with no coordination. The report suggests fixing the problem by having NSF fund equipment at private observatories in exchange for viewing time by outside astronomers.

NSF is blamed for shortchanging astronomy and astrophysics, noting that the fields have not shared proportionately in the agency's budget increases in recent years. During the 1990s, about 65% of NSF's budget for astronomy went to such facilities as the National Optical Astronomy Observatory, the National Radio Astronomy Observatory, the National Solar Observatory, and the National Astronomy and Ionospheric Center, while 22% was available for individual investigators and the remaining funds for instrumentation and university radio observatories. As a consequence of this allocation process, national facilities have cut services, maintenance, and improvements. Moreover, even as the number of astronomy proposals to NSF increased by about 50% between 1990 and 1999, the number of grants declined by 30%.

If previous decadal surveys are any guide, the new report should be well received on Capitol Hill and at the White House budget office. The four major projects proposed by Bahcall's 1991 committee have either been built or are under construction; the same is true for nine out of 11 moderate-sized projects. Though a space telescope was first suggested by Hermann Oberth in the 1920s and championed by Princeton University's Lyman Spitzer in the 1940s, it only ranked ninth among the priorities of US astronomers in 1972, when the survey committee was chaired by Jesse Greenstein of Caltech. But NASA's enthusiasm for a somewhat smaller version won Congress's support for the space telescope, later named for Edwin Hubble. The 1982 survey, headed by George Field of the Harvard–Smithsonian Center for Astrophysics, recommended the Very Long Baseline Array, capable of milliarcsecond imaging and the 8 m twin Gemini telescopes, both of which were delayed by tightened federal budgets during the 1980s and the Challenger space shuttle disaster in 1986. Field has calculated that about 60% of the 1992 recommended concepts were adopted. "I was grateful to the agencies for backing our recommendations before Congress and to Congress for its financial support despite the country's pressing problems," he says.

The reason that astronomers have been so successful in the past on Capitol Hill, says William Wulf, president of the National Academy of Engineering and the NRC's vice chair, is because "these are not typical 'please send money' reports. They represent some tough decisions." Bahcall characterizes the decadal surveys as a "heart-wrenching" process in which astronomers "have to turn down proposals that were sometimes a decade in the making. That's one reason the reports are so credible."

Early in its deliberations, the committee asked NASA and NSF how fiscally conservative it should be in proposing expensive new instruments and was told to "be bold" and "not to restrain ourselves," said Taylor.

**IRWIN GOODWIN**

# Washington Ins & Outs

## Rosenfeld, Creedon and Kelly Advance

Barely four months after leaving the Department of Energy (DOE) last December to cofound the Center for Energy and Climate Solutions (CECS), a nonprofit consulting organization in Annandale, Virginia, **Arthur H. Rosenfeld** was surprised to learn on 4 April that he had been appointed by California governor Gray Davis to the California Energy Commission. As the only scientist among the five commission members, each serving rotating five-year terms, Rosenfeld expects to have a "bully pulpit" for expressing his ideas on energy policy and planning, which have been shaped by his career as professor of physics at the University of California, Berkeley, as founder and director of the Center for Building Science at Lawrence Berkeley National Laboratory, and at DOE, where he served since 1994 as senior adviser to the assistant secretary for energy efficiency and renewable energy.

Though Rosenfeld was pleased by the news of his appointment to the California Energy Commission, he was nonetheless pained to give up his participation in CECS. The other CECS cofounder, **Joe Romm**, left DOE last year to form the organization. Rosenfeld characterizes Romm as his "most productive and stimulating collaborator" at DOE. After receiving a PhD in physics from MIT in 1987, Romm worked in the early 1990s with Amory Lovins, the influential energy and environmental guru at the Rocky Mountain Institute. Lovins recommended Romm to Hazel O'Leary, then Secretary of Energy, who snapped him up as principal deputy to the department's assistant secretary for energy