Section II-5

research and data analy

Underpinning the space science flight programs are two programs of space science activities called Research and Analysis (R&A) and Data Analysis (DA)—collectively called Research and Data Analysis (R&DA). Broadly put, research supported under R&DA programs develops the theoretical tools and laboratory data needed to analyze flight data, makes possible new and better instruments to fly on future missions, and analyzes the data returned so that we can answer specific questions posed and fit them into the overall picture. Although priorities within both programs are established in accordance with the Enterprise strategic goals, the program types differ in scope. While DA programs are tied to specific missions, which are focused on the achievement of specific strategic objectives, the scope of R&A programs is generally wider

because they must provide the new theories and instrumentation that enable the next generation of flight missions.

The alignment of R&A programs with Enterprise strategic goals is ensured through two mechanisms. First, NASA Research Announcements soliciting R&A proposals contain explicit prioritization criteria with respect to Enterprise objectives. Second, the entire R&A program is reviewed triennially to assess scientific quality and productivity of the major components and to adjust plans to best support Enterprise goals.

Data Analysis (DA) programs have traditionally been performed by mission instrument teams and interdisciplinary scientists competitively selected for an individual mission for the lifetime of that mission. For some missions or mission groups, periodic open and competitive solicitations enable DA participation by other investigators. As a matter of principle, the Enterprise has begun to add annual, open and competitive DA solicitations to all missions that can accommodate "guest investigations."

Without a vigorous R&DA program it would not be possible to conduct a scientifically meaningful flight program. Examples of the contributions of the R&DA program abound across the whole frontier of space science.

Role of NASA's Research and Data Analysis Programs

In a recent study (*Supporting Research and Data Analysis in NASA's Science Programs: Engines for Innovation and Synthesis*, National Research Council, 1998), the Space Studies Board identified R&DA functions that are "integral elements of an effective research program strategy":

- Theoretical investigations
- New instrument development
- Exploratory or supporting ground-based and suborbital research
- Interpretation of data from individual or multiple space missions
- Management of data
- Support of U.S. investigators who participate in international missions
- Education, outreach, and public information

Objectives of R&DA Programs

Theoretical, modeling, and laboratory work provide the tools to understand and integrate measurements made in space and on the ground, and can also directly impact future mission concepts. Numerical modeling of impacts and magnetohydrodynamics support both planning for future missions and understanding of data returned from past ones. Laboratory experiments, in turn, are used to validate these theoretical results. The R&A-supported laboratory work on meteorites underpins research on asteroids, as well as continuing analysis of fragments that are believed to have come to Earth from Mars. In a different vein, models for the atmosphere of Mars can be used to predict the performance of aerobraking systems for future spacecraft. The R&A Planetary Protection Program is developing methods to completely sterilize ice-penetrating probes so that we can one day confidently search for life on Europa without fear of a spurious detection due to contamination from Earth. And sample returns from Mars cannot be undertaken until the possibility of contamination of our own planet is fully understood and eliminated.

Exciting new revelations about the cosmos are not possible without the most **advanced detector and instrument systems** that can be built, most of which are developed through competitively-selected space science R&A programs. Many are given real-life testing in the sounding rocket and balloon programs before the decision is made to fly them on the much more expensive Earth-orbiting and deep space spacecraft. The new-generation detectors for the Hubble Space Telescope, the Chandra X-ray Observatory, Solar and Heliospheric Observatory, and the upcoming Space Infrared Telescope Facility were largely developed within the R&A program. Similarly, future generations of instruments slated for possible use on our planetary missions are being designed and built within the R&A program. As illustrated in the table "Examples of Flight Hardware with R&A Heritage" (p.89), instrument concepts developed through the R&A program have been the basis for flight instrumentation for every class of NASA flight mission, from the smallest to the Great Observatories.

Time exposure of a hypervelocity oblique impact, from the right of the frame. Low-angle impacts cause the projectile to fragment, and significant pieces survive to disperse downrange without much change in velocity. (NASA Ames Vertical Gun Range)

After we have obtained them, we must **analyze and interpret data** returned by NASA's space science missions to fully exploit them for addressing our strategic science objectives. R&A and DA support the necessary advanced modeling and theory. For example, recent computational modeling of the convective upwelling in Europa's ice shell has been used to interpret the "blisters" observed by the Galileo spacecraft to estimate the thickness of the shell and the depth of a possible liquid water ocean beneath it. Other Galileo data have been analyzed to reveal the physical state and major dynamical processes within Jupiter's turbulent atmosphere and on the surfaces of the giant planet's diverse satellites. Our understanding of the effects on Earth of the nearest star, the Sun, is progressing as a result of interpretation of data from such missions as the Solar and

Examples of Flight Hardware with R&A Heritage

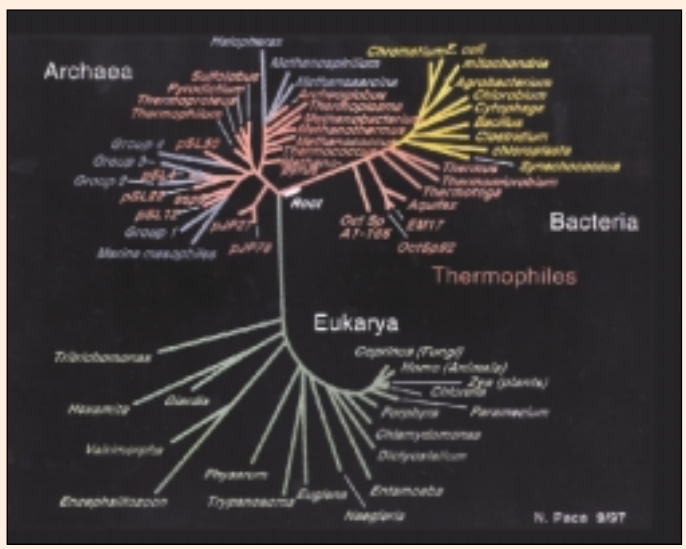
Chandra	Focal plane detectors
Cluster	Electron and ion analyzer predecessors
EUVE	Wedge and strip detectors
	Mirror
FAST	Wave-particle correlator
	Multiple-baseline electric field interferometer
FUSE	Holographic grating
	Delay-line detectors
	Mirror
Galileo	Ebert-Fastie spectrometer
Hubble Space Telescope	Multi-anode microchannel plate array detector
Lunar Prospector	Electron reflectometer
SNOE	X-ray photometer
SOHO	Ultraviolet spectrometer
	Delay-line detectors
	Multi-layer imaging
TIMED	Ultraviolet imager
TRACE	Normal incidence multilayer filters
Wind	Wave-particle correlator
	Electron and ion analyzer predecessors
Yohkoh	Glazing incidence x-ray optics

Heliospheric Observatory (SOHO) and the Transition Region and Coronal Explorer (TRACE). A very practical example is coronal mass ejections, which directly affect—in some cases permanently damage—Earth-orbiting communications satellites. A complete understanding of these ejections could have very significant benefits to our national security and to the space communications industry. In the more remote universe, R&DA supports investigations into one of the long-standing enigmas in astrophysics, the nature of gamma ray bursts. During brief flashes, these objects scattered over the sky are individually the brightest objects in the universe. A major advance was recently achieved when the visible counterpart to one of these bursters was observed simultaneously with its detection in gamma rays. Equally exciting, fine details of the fossil microwaves remaining from the Big Bang were revealed for the first time by one of a series of balloon-borne experiments from the Antarctic.

Vast amounts of data are returned from space science missions. The volume, richness and complexity of the data, as well as the need to integrate and correlate data from multiple missions into a larger context for analysis and understanding, present growing opportunities. Exploration and discovery using widely distributed, multi-terabyte datasets will challenge all

Looking at the World in New Ways

R&A supported work that revealed the existence of a distinct and perhaps ancient type of microorganism, first christened *archaeabacteria*. Further studies supported this initially controversial theory. When the genomic sequence of *Methanococcus jannischii* was published, our perception of the taxonomy of life on Earth was sweepingly revised to today's three domains: bacteria, eukarya, and archaea. NASA-supported researchers thus discovered a previously unrecognized branch of life on Earth, an advance with profound implications for the search for life elsewhere in the universe.

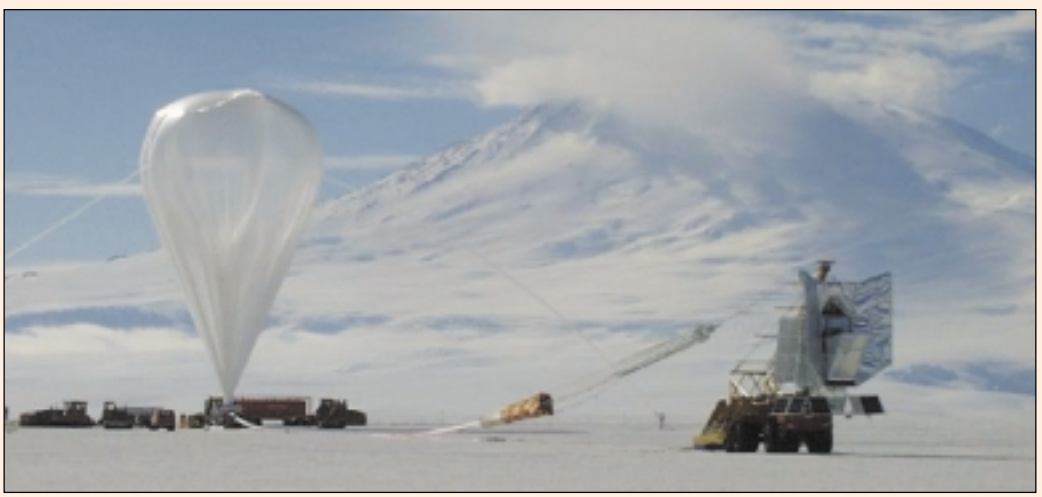


aspects of **data management** and rely heavily on the most advanced analysis and visualization tools. The design and implementation of the next generation of information systems will depend on close collaboration between space science and computer science and technology.

An example of such a collaboration is a National Virtual Observatory (NVO) initiative to collect most of the Nation's astronomical data, along with advanced visualization and statistical analysis tools. This will support "observations" and discovery via remote access to digital representations of the sky in all wavelengths. The NVO will provide multi-wavelength data for millions of objects, allowing discovery of significant patterns from the

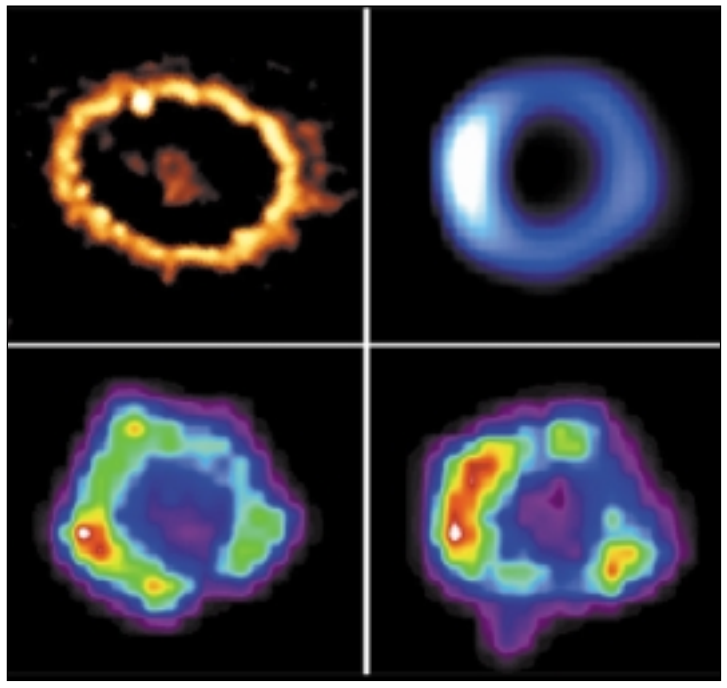
Accelerating Scientific Progress

BOOMERANG was designed to image the Cosmic Microwave Background (CMB). Work on BOOMERANG began shortly after the first detection of anisotropy by the COBE spacecraft. Though COBE detected anisotropy in the CMB, it was not able to resolve it. The challenge was to construct an experiment that could image the CMB with *40 times the angular resolution and 100 times the instantaneous sensitivity of COBE.* This was achieved by the BOOMERANG instrument, which was launched on a 10-day Antarctic voyage in late 1998, carrying a detector that had not existed just four years before. The results offer the first strong confirmation of the idea that the universe underwent a period of violent “inflation” during the first nanosecond after the Big Bang.



The BOOMERANG Telescope being readied for launch near Mt. Erebus in Antarctica. The 28 million cubic foot ballon carried the BOOMERANG telescope to an altitude of 120,000 feet, above 99 percent of the atmosphere.

exploration and mining of the statistically rich and unbiased databases. Another example is the data management and computing challenge posed by the Living With a Star (LWS) initiative. Special challenges posed by LWS include high performance computational methods for theoretical modeling and simulation, complex data analysis and visualization tools, correlative data analysis and visualization capabilities across widely varying spatial and temporal scales, and assimilation of observational data into theoretical models.



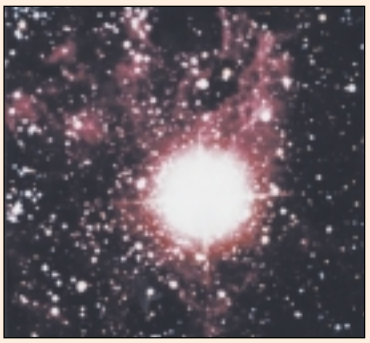
Images of the supernova SN1987A; combining information from several wavelengths helps unravel the mechanisms of astronomical phenomena. Clockwise from upper left: HST optical image; Australian Telescope Compact Array radio image; Chandra x-ray images from January 2000 and October 1999.

Setting the Stage for Future Missions

The Galileo mission has provided evidence that Europa has a liquid water ocean beneath its frozen crust, leading to speculation about possible sources of energy to support life in this ocean. Studies have indicated that without a ready supply of oxidized chemical species, the energy available for life would be minimal and any life on Europa would be very limited and difficult to detect. However, a recently developed alternative theory has revealed a novel pathway for chemical energy to be delivered to Europa. In this scenario, the intense radiation field surrounding Jupiter would produce oxidized and reduced carbon species that would be available to support life. This result is a vital consideration for the design of missions to search for life on Europa because it suggests searching the near-surface rather than penetrating kilometers of ice.

Responding to Unexpected Opportunities

On February 23, 1987, astronomers detected the first nearby supernova in 400 years. For the gamma ray measurements critical to understanding how new elements are formed in such a massive stellar explosion, NASA turned to its suborbital program as the only possible way to take advantage of this unprecedented but short-lived opportunity. A campaign of scientific balloon flights using gamma ray telescopes developed under the R&A program provided crucial evidence of how supernovae produce the heavy elements we see on Earth. Combined with observations from the ground and from space at other wavelengths, these gamma ray observations were key to developing a comprehensive picture of this stellar explosion.



Supernova SN1987A

Enabling a New Science

One of our most compelling questions is whether or not we are alone in the universe. If we are not, how does life emerge and evolve elsewhere in the universe? In fact, how did it appear on Earth? What is the future of life on Earth? These questions are the focus of the **astrobiology and exobiology** R&A program. Astrobiology has been at the forefront of an effort to break down discipline barriers to promote vigorous research at the boundaries between traditional scientific disciplines. Scientific debate on the potential for life on Europa, and even speculation on its possible nature, are recent examples of the resulting cross-disciplinary research that could motivate future missions.

To stimulate progress in astrobiology, the Space Science Enterprise recently created the Astrobiology Institute. The new Institute is an innovative virtual organization in which scientists throughout the country coordinate their research—and soon will be carrying out experiments—via high-speed computer links. It may be the most practical and efficient way to harness the highly diverse expertise of a geographically dispersed investigator population. The Astrobiology Institute will pioneer the technology that will enable teams of researchers and equipment scattered around the country, or even the world, to carry out front-line investigations.