CHAPTER

# 6
# Research and Analysis

***Keyhole Nebula, approximately 8,000 light-years from Earth. The vantage point of space reveals details of the nebula invisible from the ground. Image: NASA/HST***

**...to develop new experiment concepts,**

**and to create and to test theories of our Origins.**

The Origins Research and Analysis program provides scientists with the opportunity to explore innovative ideas and technologies that lead to better understanding of astrophysical concepts and methods. This fundamental research is crucial to achieving the scientific goals of the Origins program, and provides the basis for many future mission concepts.

The goal of the Origins Research and Analysis (R&A) program is to provide the seed opportunities for scientists to investigate innovative ideas and to do the fundamental research required to enable the scientific objectives of the Origins theme. Theoretical research and laboratory astrophysics, combined with analysis of data from ground and space observations leads to increased understanding of astrophysical phenomena and forms the basis for mission concepts. Innovative technology development begins in the R&A program through laboratory proof-of-concept demonstrations and the flight of instrumentation on suborbital platforms such as sounding rockets or balloons. The R&A program also offers strong connections to universities and is the breeding ground for future space scientists and engineers. Finally, the loop is closed in the R&A program where the return on investment in flight missions is reaped through the analysis and interpretation of data.

## Creating the Tools of Investigation

High-resolution imaging and spectroscopy at wavelengths ranging from the ultraviolet to the submillimeter is required for a variety of studies, including those addressing the inflow and outflow of gases, the structure of the cosmic web, radial and vertical disk structure, grain growth chemistry, chemical composition of the interstellar and intergalactic medium, and the characteristics of planets around other stars. In order to develop the required knowledge and technical capabilities, R&A efforts need to be focused in the areas of detector development, mission supporting technology, suborbital payloads, laboratory astrophysics, and origins of solar systems.

### *Detector Development*

The study of star and planet formation, interstellar dust, and very distant and dusty objects calls for innovative detectors in the infrared and submillimeter portion of the spectrum. Impurity band conduction arrays, such as those aboard the Space Infrared Telescope Facility (SIRTF), have proven remarkably successful, but must be further improved for the Stratospheric Observatory for Infrared Astronomy (SOFIA), the James Webb Space Telescope (JWST), and the next generation of infrared missions. New large format low read-noise and low dark current, near-infrared arrays are vital to the success of JWST. For other large infrared missions of the future, including the Terrestrial Planet Finder (TPF), a new generation of true photoconductor arrays, gapless bolometer arrays, or altogether new sensing technologies will be required. For the far-infrared/submillimeter bands, further developments in coherent detectors will be required. In addition to advancing the state of the art of the

Amazing Space is a set of web-based activities developed for the classroom. The program was designed to enhance students' science, mathematics and technology skills using recent data and results from NASA's Hubble Space Telescope. The resulting online multimedia resources are the culmination of five-week summer workshops that partnered teachers with scientists, graphic artists, writers, and multimedia developers.

Each activity is a fun, interactive way to explore a topic that adheres to National Education Standards for the target age group. All activities include a teacher guide that helps prepare educators to present the lesson in the classroom. In the guide, teachers find "science background" information, vocabulary, and detailed topic information.

In the future, the Amazing Space website will be updated with additional downloadable materials. The materials developed for educators and learners of all ages are accurate, classroom-friendly, visually appealing, as well as carefully crafted to adhere to National Educational Standards. By producing and sharing classroom resources based on the Hubble Space Telescope's discoveries, the Formal Education Group hopes that visitors, young and old, will enjoy learning about the universe.

detectors themselves it will be important to improve upon the readout technology used by infrared and submillimeter detectors.

In the ultraviolet range, a multifaceted approach is needed to develop more efficient detectors. New circuit designs, backside treatments, mosaicing, multiple device packing, and charge injection techniques are needed to improve the performance of CCDs in the ultraviolet. Research on superconducting devices (such as superconducting tunnel junctions and transition edge sensors) suggests that they have good sensitivity over the entire UV range and provide broadband imaging, time tagging, and low-resolution, high-efficiency spectroscopy. Looking ahead to space astrophysics missions of the future, complementary metal-oxide semiconductor (CMOS) active pixel sensors (APS) technology offers extraordinary advantages over current CCDs.

An emphasis on early detector research is crucial to the scientific success of a new mission. Concepts for detectors on several missions including the Hubble Space Telescope (HST), the Far-Ultraviolet Spectroscopic Explorer (FUSE), and SOFIA were initiated in the R&A program and brought to fruition in the focused technology program described earlier.

### *Mission Supporting Technology*

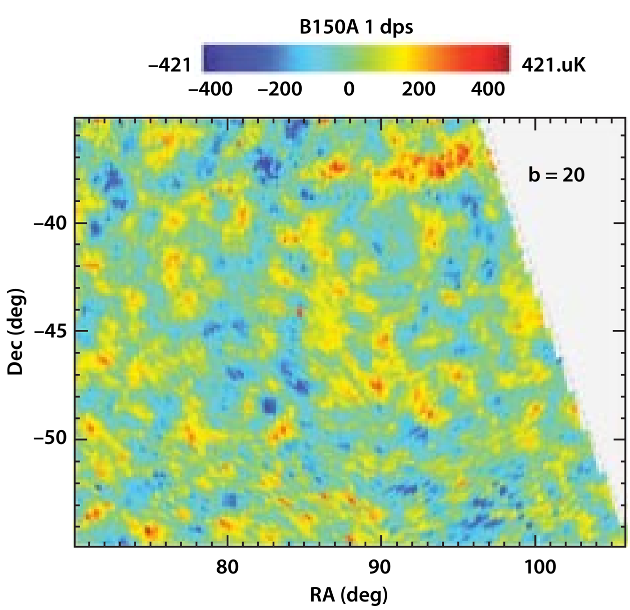
The R&A supporting technology program supports the development of innovative proof-of-concept ideas in a broad range of technologies that are relevant to the theme's objectives.

In the UV, the development of anti-reflective coatings for mirrors and gratings is an important area. Efficient grating designs, solar blind filters, grid filters, UV calibration lamps, focal plane shutters, interferometers, holographic gratings, and visible coronagraphs are some of the supporting technologies in need of further development.

Improved filter technologies which deliver larger diameters and extend spectral coverage to longer wavelengths are needed in the IR regime. In addition, cold analog-to-digital converters and improved support electronics are ripe for development.

### *Suborbital Payloads*

The R&A program offers an excellent opportunity to develop small payloads for suborbital flights. In particular, balloon or Shuttle-borne payloads produce cutting-edge science. Sounding rockets can also be used as technological testbeds. Such flights not only help to develop state-of-the-art technol-




*Sound waves in the embryonic universe are revealed for the first time in this image captured by the BOOMERANG balloon-borne telescope during its maiden voyage around the Antarctic. The patterns visible in the image are consistent with those that would result from sound waves racing through the early universe, creating the structures that by now have evolved into giant clusters and super-clusters of galaxies.*

The National Virtual Observatory will connect digital sky surveys, observatory and mission archives, and astronomy data and literature services into a single framework, enabling investigations otherwise too resource intensive to undertake.

ogy, but also constitute a high yield investment in human capital. Investigators that come through the program have gone on to become principal investigators of flight missions, major instrument builders, and astronauts.

### Laboratory Astrophysics

By utilizing a combination of laboratory experiments, modeling, and theoretical calculations, the laboratory astrophysics program provides the fundamental knowledge needed to make sense of data collected by space missions or to plan them. Laboratory measurements are often an essential link between observations and scientific conclusions. The program explores a tremendous breadth of topics, from the very coldest regions deep in molecular clouds to the extraordinary environments around super-massive black holes. It supports NASA's space missions from conception to completion, defining mission parameters and providing post-flight analysis.

Ultraviolet laboratory spectroscopy supports observations which test cosmological models and provide a better understanding of the processes that created the elements during the Big Bang. Spectroscopic data are key to interpreting visible and UV spectra of important interstellar molecules, such as the large organic species and diffuse interstellar bands (DIBs) that may be connected to the origin of life. Finally, combining laboratory results with space data provides insight into the ages and metallicities of galaxies, the sequence of galaxy formation, as well as the energetics of interstellar dust in a variety of environments.

Fine structure transitions of atoms and atomic ions in the far-IR/submillimeter are the main cooling lines of the non-ionized interstellar medium. This makes them key contributors to gravitational collapse, and as such they are critical to understanding the formation of stars and planets. IR/submillimeter transmissions of interstellar dust grains indicate specific mineral and carbonaceous composition, leading to grain opacities in various environments. These opacities, uncertain now by an order of magnitude, are key to estimating the temperature and mass of the interstellar medium within entire galaxies.

Perhaps most importantly, future missions will study Earth-like planets and search for signs of life. Laboratory experiments have shown that some of the raw materials for life on these planets can be created in interstellar grains of ice and dust. It is vital to continue these experiments, as well as others aimed at understanding the potential biosignatures observable spectroscopically on these planets from space missions.

### *Origins of Solar Systems*

The search for new solar systems by ground-based techniques has been extraordinarily successful in the last several years. These searches can be expected to be increasingly successful in the next several years and represent crucial inputs to the design of the TPF mission. The R&A program will continue to support these searches and will broaden the range of techniques and opportunities.

However, the TPF program will require more than just an inventory of the nearby planets. We need to understand how planetary systems formed, what determines their stability, and what determines the size of planets. These are research topics to be pursued in the Origins R&A programs.

If the answer to "Are we alone?" is yes, we need to have the background theoretical basis to understand why we are unique.

## Theory and Data Analysis

Before a space mission can be designed, the scientific objectives of the program must be firmly supported by observation and theoretical calculation. Recognizing this, the Origins program includes important support for theory and archival research.

### *Theory*

Theory provides the fundamental quests for our programs, predicts observable and measurable phenomena, and drives mission and payload design requirements. Theoretical tools are required for the extraction and interpretation of essential science from observational data.

Theoretical studies of early stars, galaxy formation processes, the physical processes of star, planet, and disk formation and evolution, and models in direct support of the search for extrasolar planets are all essential to the Origins program.

### *Archival Research*

As data from previous and ongoing NASA missions accumulate, the value of archival research mounts. Through the multi-wavelength data already available, researchers have gained a much better understanding of a variety of important and interesting astrophysical phenomena without ever using a telescope. Such gains range from establishing universal relations between disparate emission phenomena such as the radio-infrared correlation in star-forming galaxies, to the identification of rare "Rosetta-Stone" objects by comparing multimillion lists of sources from different wavelengths. Though current wavelength-specific archives are readily available, their contents are growing exponentially in both content and diversity. The development of more sophisticated software tools permitting queries spanning all available archives would prove invaluable to scientists. Such a collection of tools would constitute a National Virtual Observatory, a powerful new research capability enabling investigations otherwise too resource intensive to undertake.