



Harvard-Smithsonian Center for Astrophysics

Science Strategic Plan

Executive Summary

Mission Statement

"The mission of the Harvard-Smithsonian Center for Astrophysics is to advance our knowledge and understanding of the Universe through research and education in astronomy and astrophysics."

Introduction

At the Center for Astrophysics we engage in forefront research in many different ways, from small individual projects to research centers to the utilization and operation of unique major ground- and space-based facilities. We excel as observers, theoreticians, instrumentalists and laboratory experimentalists. Our research spans the breadth of the electromagnetic spectrum, helping to create the distinctively fertile research environment that is the underpinning of our success. Our vision is to remain the leading center in multi-wavelength observing while strengthening our theoretical, computational and laboratory astrophysics efforts. How best to sustain and strengthen our Center is a challenging matter. The opportunities for breakthroughs in our field are numerous – this is the new “golden age” of astronomy – and they beckon our full participation.

The Science Strategic Planning Committee (SSPC) was charged by the Director with determining which new facilities and programs will best suit our distinctive competencies. For the past year this committee, comprised of members from the scientific divisions, crafted this strategic plan to accomplish two objectives:

- 1. identify those new facilities and programs that tackle the most important science goals of our generation, make maximum use of our expertise in these areas, and promise the most significant benefit to our research, and*
- 2. establish an appropriate balance between these few strategic projects and the important research carried out by our colleagues as individuals and in small groups.*

These twin objectives will guide the participation in new opportunities and the allocation of resources over the coming decade. We will optimize the capabilities of our current facilities and centers even as we seek lead roles in several “next-generation” facilities and missions. The plan addresses our need for better and larger physical facilities, high-speed, high-performance computing capability and better ways to attract the best and the brightest scientists and students. The committee also notes that improved communications – internal and external – are critical to our future success.

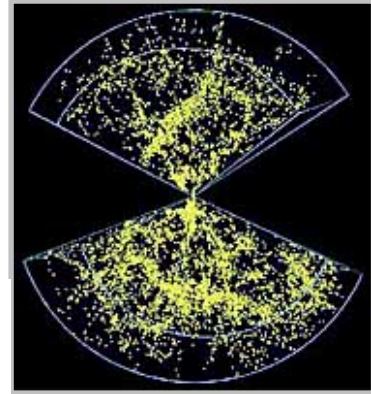
Science Drivers

The committee has organized the plan around four themes that exploit our current strengths and that we expect will be extremely fruitful in the next ten years. These clear science goals draw on our distinctive capabilities and require significant Center resources. These themes are:

Inflation, Dark Matter and Dark Energy

Working from the standard model of the “Big Bang” some 14 billion years ago, we’re investigating the early epoch of inflation and the nature and role of dark matter in the evolution of structure in the Universe. We also seek to understand the nature and properties of the “dark energy” that is speeding up the expansion of the Universe.

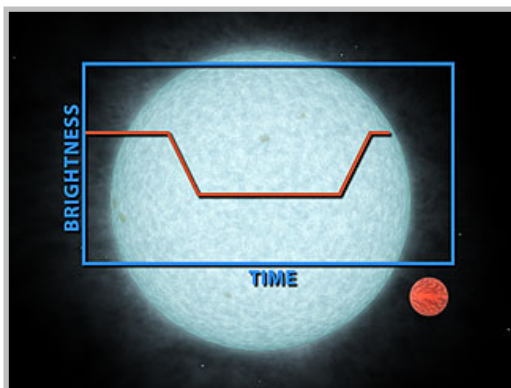
Right: A map of the distribution of galaxies in the Universe. The CfA pioneered the mapping of galaxies and made the first surprising discoveries about the large-scale structure of the Universe: that the galaxies are not uniformly scattered throughout space, but are instead clumped into huge bubbles and filaments.



Galaxies and Black Holes

Soon after the Big Bang, the Universe became a space filled with “stuff:” neutral gas, dark matter, and radiation. After several hundred million years, primitive structures began to form from the first chemical elements, creating the first massive stars and eventually the first galaxies. We want to know how they formed, how they interact, and the processes that create supermassive black holes.

Right: Spiral galaxy M81, image taken by the Infrared Array Camera on the Spitzer Space Telescope. The unprecedented sensitivity of the infrared camera shows regions of intense star formation, and the glow of the interstellar gas that is excited by the birth of the new stars.



Stars and Planets

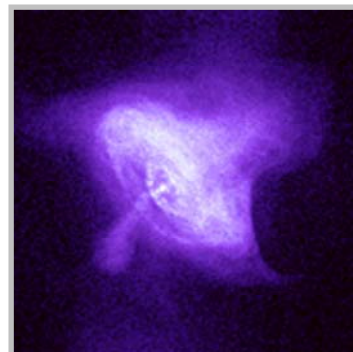
We think we know how stars live and die, but our picture of how stars form to begin with is incomplete. Although astronomers have discovered well over 200 planets in other solar systems, we do not really know what conditions actually produce life. We seek to resolve major uncertainties about the complex processes that lead from clouds of gas and dust to stars, planets, and the emergence of life.

Left: In 2005, a CfA scientist led the team that made the first direct detection of the light from a planet in a distant solar system. Using the Spitzer Space Telescope, the astronomers combined the light before and after the planet passed behind its parent star during its orbit to characterize the light reflected by the planet only.

Extreme Astrophysics

The most violent and energetic phenomena in the Universe are gamma-ray bursts, the birth of neutron stars or stellar black holes in supernovae, whose huge explosions release the basic elements from which life formed, including us. Because the physical conditions in these phenomena can't be replicated in our Earth-bound labs, we must develop and use new tools to unlock the extreme physics of our Universe.

Right: This 1999 image of the Crab Nebula was taken by the Chandra X-ray Observatory. It shows the detailed structures of waves radiating out from a rapidly spinning pulsar at the collapsed star's center. CfA played lead roles in designing the x-ray telescope and its high resolution camera. SAO also operates the spacecraft from a control center in Cambridge, MA.



Priorities and Balance

The highest priority new initiative for the Center for Astrophysics is to play a leading role in the development and operation of the exciting new Giant Magellan Telescope (GMT). Our goal is to obtain 20-25% share of the observing time with this facility. The large collecting area and high angular resolution of this next generation optical/IR telescope will enable critical investigations central to all four of the science themes identified above.

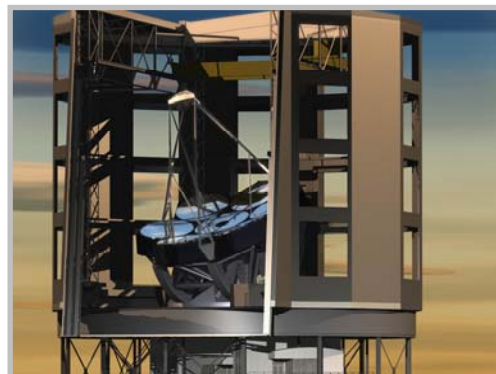
CfA participation in new NASA activities is of critical importance to the Center's future, in particular, high energy astrophysics missions.. Constellation-X (Con-X) is one of just two Beyond Einstein (BE) flagship missions, and it is the CfA's highest priority space astrophysics program. The CfA is partnered with NASA's Goddard Space Flight Center (GSFC) to provide the science leadership for this major facility, an important function for the science breadth and balance of the Center. Con-X and other post-Chandra missions require new technology, and the CfA should lead these developments. Accordingly, ***the Center for X-ray Technology (CXT) will provide critical strategic leadership in new optics and detectors for the nation's space astrophysics program.***

These two major initiatives are extremely demanding intellectually and financially. We will aggressively seek support for them, and contribute intellectual and technical leadership to their development. Our research program requires that we balance these initiatives with a portfolio of programs that span the range of scales from the very large to modest, including ground-breaking projects where higher levels of risk can be tolerated (even encouraged). The major elements of this balanced program are:

New Facilities:

The Giant Magellan Telescope (GMT)

The GMT is a planned ground-based optical/infrared telescope with the resolving power of a 24.5-meter mirror, comprised of seven 8.4-meter diameter segments. The GMT is scheduled for commissioning in 2016. Our goal is to support a 20-25% share of telescope observing time and to develop first light instruments, particularly the near-IR multiobject spectrograph. The GMT addresses all four science themes. We will use the GMT for direct detection of light from terrestrial and gas giant planets; measurements of the large scale structure and evolution of galaxies (and AGN) at redshifts of 3-5; studies of the transformation of dusty gaseous disks into planetary systems; investigations of the evolution of stellar populations in galaxies at redshifts 1-2; and the evolution of metals at redshifts 2-10.



An artist's conception of the GMT, which is likely to be built in Chile.

The Mileura Wide-field Array will be sited at one of the last remaining radio-quiet area on Earth in a remote region of Australia. One of its most important scientific goals is to study hydrogen emission to characterize the so-called Epoch of Reionization, the period approximately 150 million years after the Big Bang. The observations will tell us much about how the early Universe formed.

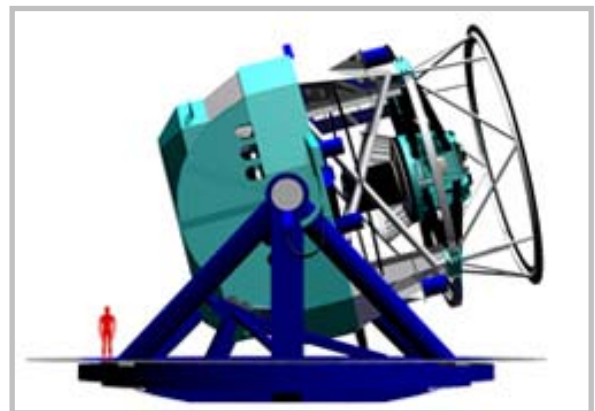


The Mileura Wide-Field Array (MWA) and the Square Kilometer Array (SKA)

The MWA/Low Frequency Demonstrator (LFD) is a low frequency radio telescope funded (in the US) by NSF and sited in Australia. The MWA/LFD is a precursor to the low frequency component of the SKA, also likely to be sited in Australia. Our goals are to start work on the LFD in mid-2006; start deployment of hardware to site in 2007; start science operations in 2009.

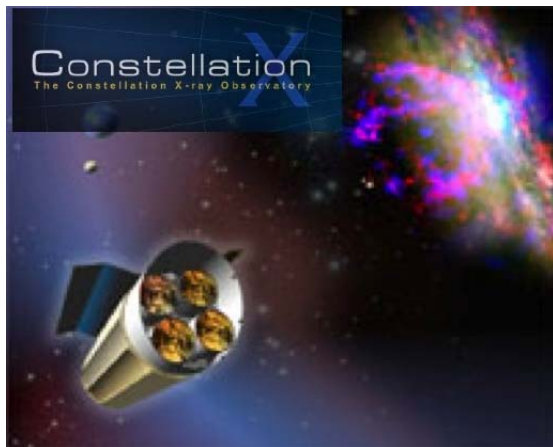
PanSTARRS and the Large Synoptic Survey Telescope (LSST)

PanSTARRS will consist of four 1.8-meter optical telescopes. The first telescope is sited at Maui, Hawaii. Funding is from the Air Force (for construction only) and partners. LSST is an 8.5-meter class optical telescope. It is funded by NSF, DOE and various private sources. It will be sited in Chile. Our goals are to participate in PanSTARRS data reduction pipeline and analysis and to continue our membership in the LSST Corporation with involvement in focal plane cameras and the data pipeline.



Above: The Large Synoptic Survey Telescope (LSST) is an international collaboration that includes the CfA. The LSST will cover the entire sky every three nights, providing massive data on such objects as exploding supernovae, near-Earth asteroids and far-distant galaxies. Observations of the latter will help characterize Dark Matter and Dark Energy.

New Missions:



Constellation-X (Con-X)

We expect to play a lead role in Con-X, one of two flagship missions of NASA's Beyond Einstein program. It may consist of several X-ray telescopes working in unison to generate the observing power of one giant telescope. SAO will operate the Science Operations Center for Con-X and will work with GSFC on pre-Phase-A systems engineering for optics, technical development for detectors and lead of Facility Science Team (2007). We plan for a major hardware role in the mission

Left: Con-X is a planned NASA space mission that will function as one large, extremely high spectral resolution telescope. Among many science questions, Con-X will study black holes, galaxy assembly and the nature of Dark Energy. It will have 100 times the sensitivity of existing x-ray telescopes.

New Centers:

Center for X-ray Technology (CXT)

CXT is located within the High Energy Astrophysics Division of the CfA, with laboratories at Cambridge Discovery Park. It will be funded by NASA grants, SAO, and private donations. Our goals are to support the staff through SI and private donations in 2006, with successful grant support via NASA, NSF, DOE, etc. in 2007 and beyond.

Right: The Chandra High Resolution Camera laboratory at SAO which designed and built the camera for the Chandra X-ray Observatory. The CXT will develop advanced technologies in optics and detectors for future NASA x-ray missions.



Ongoing Facilities:



The MMT and Magellan Telescopes

The 6.5-meter diameter telescopes are our major optical/infrared facilities. The MMT, in Arizona, is a joint project of the Smithsonian and the University of Arizona. The twin Magellan Telescopes in Chile are jointly operated by Harvard, the Carnegie Institution, MIT, the University of Michigan, and the University of Arizona. Our goals are to optimize the capabilities of these facilities, and to complete the Magellan f/5 secondary in 2007, the MMIRS instrument in 2007 and Binospec in 2009.

Above: The MMT Telescope is located on Mount Hopkins in southern Arizona; its twins are located at Las Campanas in Chile. These facilities have been crucial in many CfA discoveries, including the discovery of the first "hyper-velocity stars" being flung out of the Milky Way galaxy by their encounter with a black hole at the galaxy's center.

The Submillimeter Array (SMA)

The SMA comprises eight moveable 6-meter diameter antennas on Mauna Kea in Hawaii. The SMA is a joint project of the Smithsonian, the Academia Sinica Institute for Astronomy and Astrophysics, and the University of Hawaii's Institute for Astronomy. Our goals are to continue operations and to complete high frequency receivers for polarization measurements; expand the SMA to include the Caltech Submillimeter Observatory and the James Clerk Maxwell Telescope.



The Submillimeter Array was completed and dedicated in November 2003. Now in full operation, it can study planetary systems, asteroids, comets, planets in our own Solar System, dying as well as newborn stars, redshifted radiation from the most distant (and therefore oldest) objects in our Universe and even radiation from the Big Bang.

The Very Energetic Radiation Imaging Telescope Array System (VERITAS)

VERITAS consists of four 12-meter aperture telescopes presently sited at Mt. Hopkins, AZ. It is funded by NSF, DOE, and SAO, and operated by SAO with a collaboration of several colleges and universities worldwide. Our goals were to construct four telescopes at Mt Hopkins in 2006 and to operate them there for two years while a permanent site is determined. VERITAS will relocate to its permanent site in 2008 and potentially expand to seven telescopes thereafter.

Right: The prototype 10-meter diameter reflector that gave birth to the Very Energetic Radiation Imaging Telescope Array System (VERITAS) project. This facility studies a phenomenon called "Cherenkov radiation," a shower of charged particles in the Earth's atmosphere caused by gamma ray bursts in space.

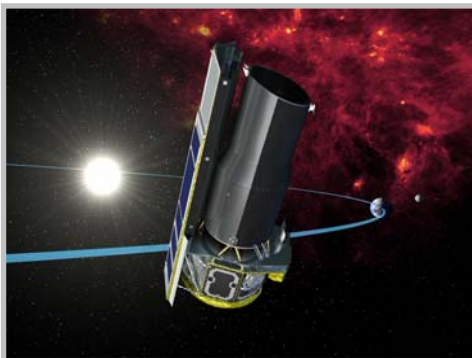


Ongoing Missions:

Chandra X-ray Observatory

The Chandra X-ray Observatory is part of NASA's Great Observatory Program. It is funded by NASA, and is operated by SAO on behalf of NASA. The Observatory is an international facility that carries out observations for several hundred GOs each year. Our goal is to continue Chandra operations beyond 2014.

Right: The Chandra X-ray Observatory is in its second six-year cycle, operated at the CfA by SAO. Chandra observations span the gamut of astrophysics from planets to clusters of galaxies – covering virtually every type of cosmic object known.



The Spitzer Space Telescope

The Spitzer Space Telescope is the infrared telescope of NASA's Great Observatories Program. SAO provided the Infra-Red Array Camera (IRAC) and the IRAC Team has guaranteed observing time on Spitzer. The project is NASA-funded. Our goal is to continue IRAC operations after 2009 (when the coolant will have been exhausted.)

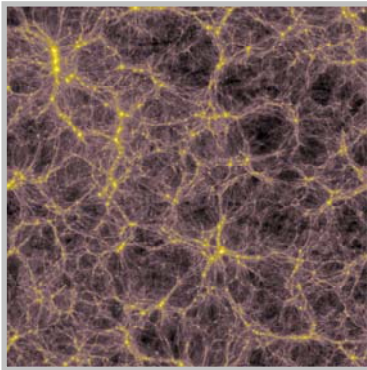
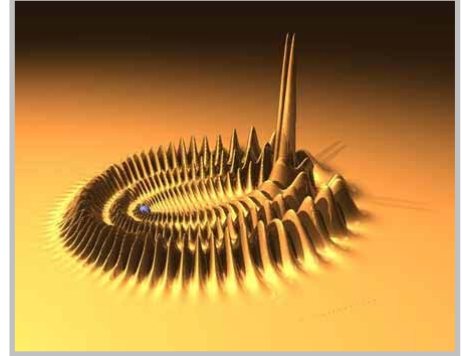
Left: Launched in August 2003, the Spitzer Space Telescope flies in an Earth-trailing heliocentric orbit that keeps it cool enough not to require large amounts of coolant on board to meet a five year mission lifetime. Spitzer's main Infrared Array Camera was designed and developed by a CfA scientist. Spitzer's infrared "eyes" penetrate dense clouds to view the birth of stars and planets, and to study the very distant Universe whose light has been redshifted into the infrared.

Ongoing Centers:

Institute for Theoretical, Atomic, Molecular and Optical Physics (ITAMP)

ITAMP is an NSF funded center of excellence jointly located and operated by CfA and the Harvard Physics Department. Our goal is to continue providing the intellectual leadership in the theoretical AMO Physics community with continued NSF funding from 2007-2011 and other grant support, possibly through DOE.

Right: The existence of a ubiquitous class of ultra-long range molecular Rydberg states was predicted by a JILA/ITAMP collaboration in 2000. These giant molecules have an electron cloud resembling a trilobite, the ancient, hard-shelled creature of the Paleozoic era. These molecules are estimated to live about 1-10 milliseconds, far shorter than the life span of a trilobite!



Institute for Theory and Computation (ITC)

ITC is a center of excellence in theoretical astrophysics. Its funding is through the Harvard Astronomy Department. Our goal is to continue our leadership in computational astrophysics through ongoing support from Harvard.

Left: A computational model of the initial perturbations that grow via gravitational instability to form a "cosmic web" of structure on many scales. Numerical approaches, including the use of a custom built set of computer clusters, are being developed at the CfA to calculate properties of this evolving structure.