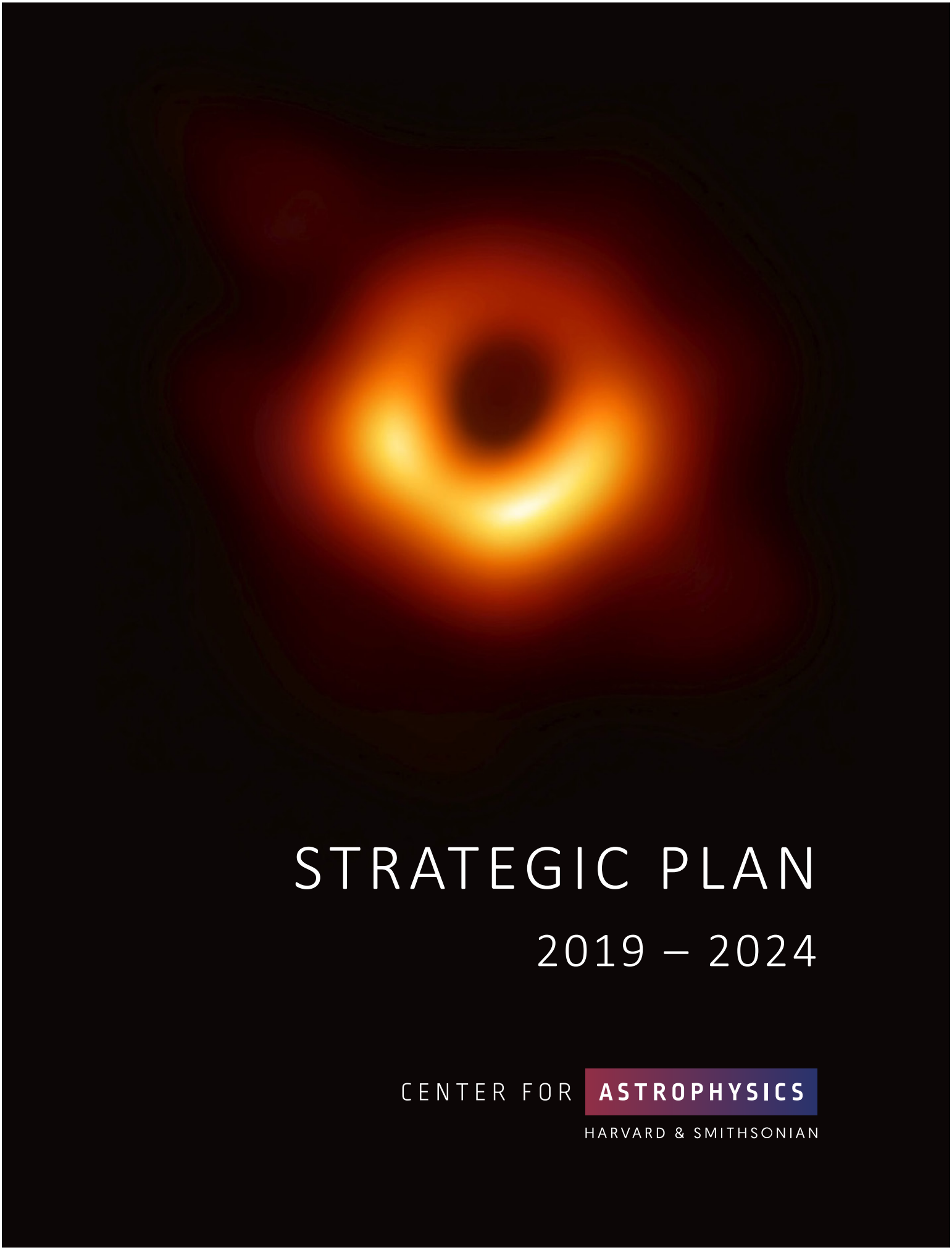


STRATEGIC PLAN

2019 – 2024

CENTER FOR **ASTROPHYSICS**

HARVARD & SMITHSONIAN

From the Director

Charles Alcock joined the Center for Astrophysics | Harvard & Smithsonian (the "CfA") as its third director in 2004. Before coming to the CfA, Dr. Alcock had been a professor of astronomy at the University of Pennsylvania. With a single director, the CfA has maintained the unified vision and strategic priorities that brought it to world leadership in the decades following its first phase of dramatic growth in the 1960s to early 1970s.

The Center for Astrophysics | Harvard & Smithsonian is the union of two distinct entities, the Harvard College Observatory (HCO) and the Smithsonian Astrophysical Observatory (SAO). Founded in 1839, HCO installed the 15-inch telescope known as "The Great Refractor" in 1847. SAO was founded in 1890 and grew to prominence first with Secretary Langley's study of the Sun. In 1955, SAO relocated to Cambridge, MA, to explore collaborations with HCO. The Harvard-Smithsonian Center for Astrophysics was established in 1972. There have been many exciting developments in the time since, and today the CfA conducts observational research across the electromagnetic spectrum, investigating the Universe at scales ranging from our own star, the Sun, to the cosmic background radiation. Theoretical and computational investigations provide explanations that force us to ask us new compelling — and difficult — questions.

The CfA substantially influenced modern astronomy and astrophysics, bringing astronomy and the laboratory disciplines ever closer together. The relationship between physics and astronomy is now mature, although some of the most important questions remain unanswered, including: What happens at the event horizon of a black hole?

Now in the 21st Century, CfA scientists are making significant connections between astronomy, physics, chemistry and biology, extending now to include the search for evidence of life on an exoplanet!

Our strategic goals are driven by the largest scientific questions facing humanity: What is the structure of the Universe and what is it made of? Where did we come from? Are we alone?

Strategic Plan 2019-2024

September 23, 2019

Sections

Acknowledgments

In anticipation of developing a strategic plan, the Director's Office engaged in a number of activities with the community over the past few years, including small group meetings and CfA-wide meetings. Our request for white papers produced 22 thoughtful suggestions. We have also presented early drafts of this plan to the SAO Advisory Board and the CfA Visiting Committees. We also acknowledge the writing and editing contribution of Amanda Preston.

I. CFA 2019: OUR DISTINCTIVE CHARACTERISTICS

Mission

The Center for Astrophysics (CfA) is a collaboration between Harvard University and the Smithsonian Institution, through our respective observatories, the Harvard College Observatory (HCO) and the Smithsonian Astrophysical Observatory (SAO). Our mission is to advance knowledge and understanding of the Universe through research and education in astronomy and astrophysics.

Programs

As one of the largest groups of astronomers and astrophysicists in the world, with some 250 Ph.D. researchers on a staff of 700 total employees, fellows, and students, we conduct *curiosity-driven* research into fundamental questions about the Universe and our place in it.

We design, develop, and carry out observational, theoretical, and experimental programs to address these questions, building and operating facilities as required. We have the breadth of expertise across the electromagnetic spectrum to probe the structure and evolution of the Universe from small to large scales. We use our combined resources to train many of the most talented students and postdoctoral fellows in the world.

Structure

The CfA is a collaboration between two very different institutions whose combined purpose is to encourage, nurture and reward individual as well as group research. Its directors, present and past, have stewarded this complicated and highly successful institution with "bifocal" attention to achieving clear goals in the near term and maintaining full readiness for a future that is envisioned but not yet established within the uniquely self-reflective field of astrophysics.

CfA's Influence:

Election to the National Academy of Sciences is one of the highest honors accorded a U.S. scientist or engineer. The Center for Astrophysics has figured in the backgrounds of many of today's Academy members. Of the 96 current members in the Astronomy section, 41% were either educated at, taught at, or served as researchers at the CfA. Today, eleven CfA scientists are Academy members, ten in Astronomy and Astrophysics, and one in Physics.

Funding

The CfA is a fiscally diverse institution, allowing significant flexibility in funding its activities. A portion of our scientists hold positions funded through the Smithsonian Institution's federal budget; others receive funding through contracts and grants to the Smithsonian. The Harvard faculty, who are distinguished researchers in addition to their teaching activities, are on University salaries. We seed new programs and support large proposal efforts through internal support, much of which derives from the indirect costs on our contracts and grants. We rely on external support from public sources, primarily NASA and the NSF, and from private sources, both individuals and foundations, some in the form of endowments. We partner strategically with many national and international institutions to carry out our long-term projects.

About This Plan

This is an excellent moment to consider the future directions in our field and the future of our intellectual leadership. This document describes the joint scientific vision of the Smithsonian Astrophysical Observatory and the Harvard College Observatory. It expresses our current and planned commitments (scientific and operational) and our planned focus on key research questions and problems for the next five years. It also speaks to the need for agility in our rapidly evolving field.

This plan will guide the allocation of resources, not only financial decisions, but also in scientist positions, administrative and technical support, and in our physical workspace. Our science goals adhere closely to the Smithsonian Institution's 2017 Strategic Plan theme, "Unlocking the Mysteries of the Universe," and to the spirit of Harvard's new leadership under President Lawrence Bacow. Our intention with this five-year plan is to present our internal CfA strategic goals on a timescale consistent with discussions to take place at the national level through the *Astronomy and Astrophysics Decadal Survey*.[1]

This document is intended for a broad audience, ranging from the leadership of our parent institutions to the visitors to our website, to our funding agencies, to our current and prospective donors, as well as to our collaborators (individual and institutional), journalists, and prospective students, fellows, researchers, technical and administrative employees.

II. BUILD MAJOR NEW FACILITIES FOR OPTICAL/INFRARED AND X-RAY OBSERVATIONS

The CfA will play major roles in two new observing facilities essential to our core research and to preserving our observational capabilities in the optical/infrared and in the X-ray regimes. This priority is a continuation of two major strategic goals originating in our 2007 Strategic Science Plan, each of which we expect to be considered in the Decadal Survey's process.

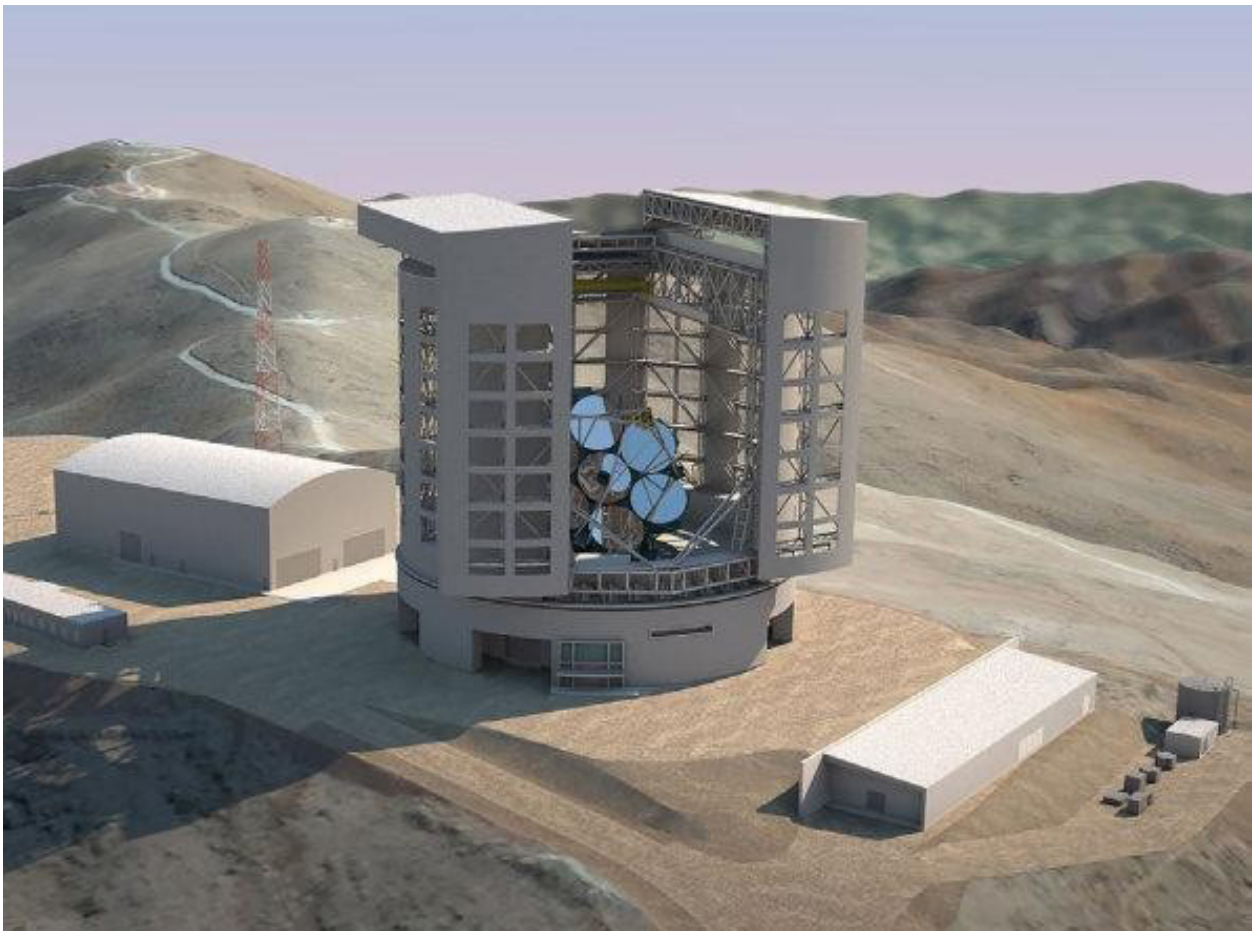
1. The Giant Magellan Telescope (GMT)

This spectacular telescope will have a collecting area equivalent to a primary mirror that is 25.2 meters in diameter. Located in northern Chile, it will operate at one of the best sites in the world for astronomy. The international partnership building the GMT comprises twelve leading institutions.[2] Our science goals for the GMT are both complementary to and synergistic with NASA's *James Webb Space Telescope* (*JWST*), as well as with other current and planned space- and ground-based facilities.

---

[1] *The Astronomy and Astrophysics Decadal Survey is an influential study run jointly between the Board of Physics and Astronomy and the Space Studies Board of the National Academies. The goal of a decadal survey is to consider the past and current research of the field and provide consensus recommendations for the direction of the field over the next decade. These recommendations are made by a survey committee which is directed by the statement of task and informed by community input. (From: http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_185159#About_the_Survey)*

[2] *Arizona State University, Astronomy Australia Ltd., Australian National University, Carnegie Institution for Science, FAPESP – The São Paulo Research Foundation, Harvard University, Korea Astronomy and Space Science Institute, Smithsonian Institution, Texas A&M University, The University of Texas at Austin, University of Arizona, University of Chicago.*



The Giant Magellan Telescope, here depicted in an artist's conception, is a seven-mirror segmented surface whose precision instruments will be mounted in the 22-story enclosure.

The CfA leads the team responsible for the extraordinary spectrograph G-CLEF (GMT- Consortium Large Earth Finder). G-CLEF, when mounted on the GMT, will significantly advance the search for and characterization of planets around other stars. It is designed to detect the presence of diatomic oxygen in the atmospheres of Earth-like planets orbiting nearby stars.

Terrestrial O_2 is produced by living organisms; these observations will usher in the study of life elsewhere in the Universe. The search for life on other planets is one of the key programs of the Harvard University Origins of Life Initiative, which brings senior members from HCO and SAO into collaboration with other Harvard scientists working on origins questions.

The GMT will also address a range of cosmological questions, including *"How do galaxies form and evolve?"* The GMACS (GMT Multi-object Astronomical and Cosmological Spectrograph) and GMTIFS (GMT Integral Field Spectrograph) instruments will allow us to spectroscopically characterize galaxies at high redshift, as they form at the end of the "cosmic dark ages." At this unexplored phase of cosmic evolution, when stars within galaxies are forming most vigorously, we may see infant galaxies formed at the start of reionization evolving into mature galaxies like the Milky Way, which we inhabit today.

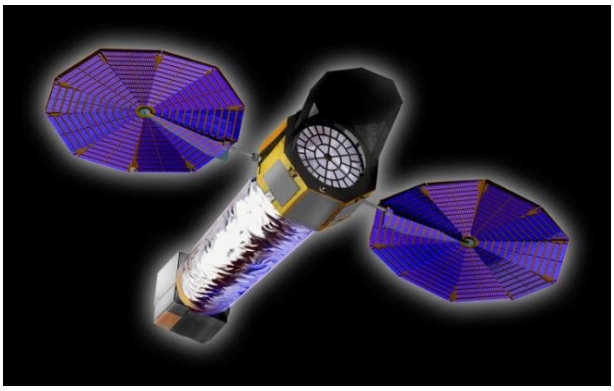
The recent observation of gravity waves from merging black holes and neutron stars, followed by the spectacular detection of electromagnetic radiation from a merger event, launched gravitational wave astronomy. We expect there will be many related discoveries made with the GMT over its anticipated 50-year life.

The CfA also participates in the GMT through active membership on the GMT Observatory Board and the Science Advisory Committee, as well as leadership in technical design reviews. CfA scientists have also played a leading role in designing the mirror alignment system.

> ***Our goals are to complete the design and construction of the GMT-consortium Large Earth Finder (G-CLEF), support the CfA community as it develops scientific plans for using the Giant Magellan Telescope (GMT), and ensure that our scientists have access to the telescope to carry out their visionary programs. As Founding Partners, we will work with the GMT Organization (GMTO) to proceed toward completion and operation of the GMT.***

2. The *Lynx* X-ray Observatory

The National Academy of Sciences' Decadal Survey for the 2020s will evaluate and compare four large, strategic space mission concepts and may select one for recommendation to NASA. Given the scope of our interests, CfA scientists will benefit from any of the missions under consideration; however, *Lynx* uniquely plays to the strengths of the CfA.

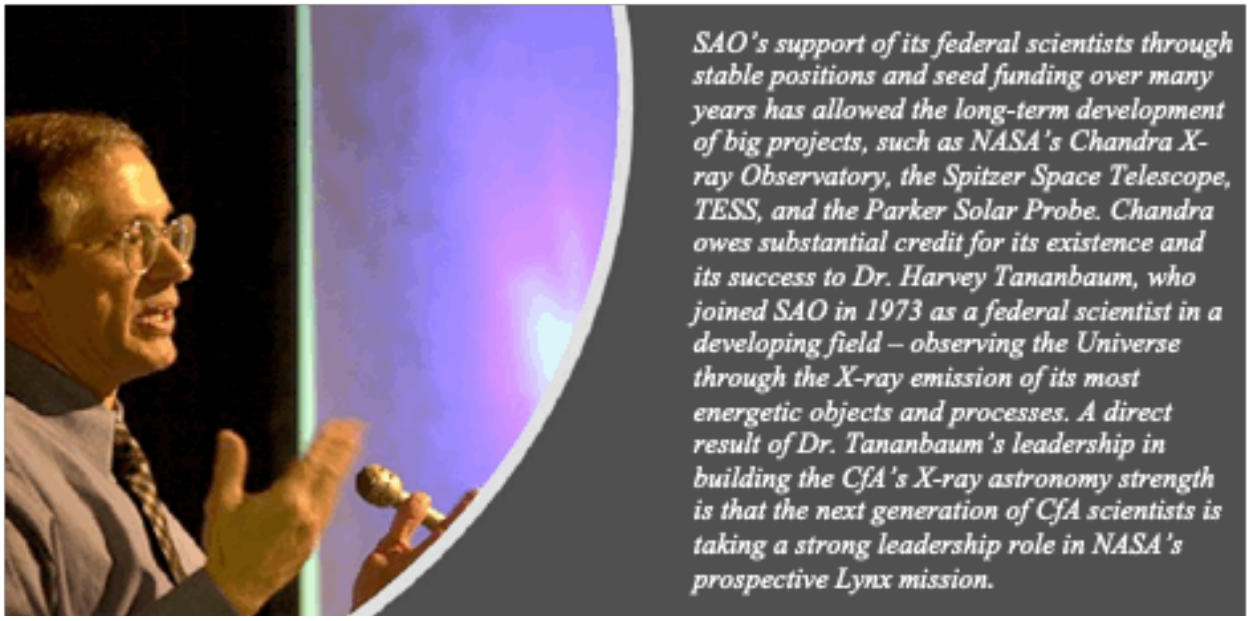


***Lynx* is being developed to address three science "pillars:" the dawn of black holes, the drivers of galaxy evolution, and the energetic side of stellar evolution and stellar ecosystems. CfA scientists work in all of these areas.**

The CfA has played a leading role in X-ray astronomy since the pioneering work of Nobel Prize recipient Riccardo Giacconi, his colleagues, and his protégés, and now hosts the *Chandra X-ray Center*. We are uniquely qualified to work on the technical development and scientific programs of *Lynx* (formerly known as the *X-ray Surveyor*). *Lynx* is a critically important successor to the *Chandra X-ray Observatory*. We note that the proposal to NASA that led to *Chandra* was submitted in 1976; *Chandra* was launched in 1999; we anticipate that the mission will continue through 2027!

Lynx will have a throughput as much as fifty times greater than *Chandra*'s, and will provide subarcsecond imaging over a twenty times larger solid angle. This combination will allow *Lynx* to reach a factor of ~100 greater sensitivity to faint point sources and survey the sky ~1000 times faster than *Chandra*. *Lynx* will be able to detect seed-mass, 10^4 $M_{\odot}$, black holes out to redshift of ~10 to establish the origin of central black holes and their role in galaxy formation. It will also measure hot gas and energetic feedback to study drivers of galaxy formation. *Lynx* and the GMT will work hand-in-hand to study stellar populations of different types and ages well outside of our immediate cosmic neighborhood. It is expected that, if selected, *Lynx* will be launched in the 2030s.

The CfA has invested discretionary resources for more than a decade in critical technology development for *Lynx*, in particular in light-weight, adjustable X-ray optics, through SAO's Internal Research and Development funding. This optics development program also receives significant NASA funding. The CfA's leadership in high resolution X-ray spectroscopy, through support of X-ray laboratory astrophysics and ongoing mission development (e.g. *Arcus*, XRISM, and *Athena*), bodes well for leadership in the *Lynx* mission. CfA scientist Alexey Vikhlinin is Co-Chair of the NASA Science and Technology Definition Team for *Lynx*.



SAO's support of its federal scientists through stable positions and seed funding over many years has allowed the long-term development of big projects, such as NASA's Chandra X-ray Observatory, the Spitzer Space Telescope, TESS, and the Parker Solar Probe. Chandra owes substantial credit for its existence and its success to Dr. Harvey Tananbaum, who joined SAO in 1973 as a federal scientist in a developing field – observing the Universe through the X-ray emission of its most energetic objects and processes. A direct result of Dr. Tananbaum's leadership in building the CfA's X-ray astronomy strength is that the next generation of CfA scientists is taking a strong leadership role in NASA's prospective Lynx mission.

Lynx is a mission concept study commissioned by NASA in preparation for the Decadal Survey. The science to be conducted with Lynx builds heavily on high energy astrophysics carried out at the CfA.

III. ADVANCE BROAD RESEARCH PROGRAMS

Balance the Strategic and the Responsive

Dr. Jennifer Yee is an early-career federal scientist studying planets with gravitational microlensing, observed as the bending of light caused by the gravitational effect of a planet (and its host star) in between a background star and the observer. The independence of CfA scientists frequently leads to important connections of their research activities to major missions and projects. Microlensing will be a key program of NASA's Wide- Field Infrared Survey Telescope (WFIRST) mission, expected to launch and search for planets in the mid-2020s.

We must be mindful that the inventiveness of individuals is critical to astronomical discovery. The CfA does now and must continue to foster creativity among its scientists. Harvard and Smith-

sonian resources are essential for this work, and are used to leverage considerable extramural support from NASA and the NSF, as well as other sources of support, including private foundations and individual donations.

It is in the nature of our community to encourage these innovations and to maintain a stable home for this diverse range of programs, whether they are research programs, new instrument studies and development, NASA mission participation, specific service to the broad astronomy and astrophysics community, exchange programs with other institutions, or the many other ways in which our scientists engage in their work and find the support that proves the value of their ideas to the community beyond the CfA.

The broad range of research in astronomy and astrophysics at the CfA makes it a unique environment for cooperation and cross-fertilization. Our size and technical diversity enable discovery within and across disciplines. Exposure to and participation in this diversity make the CfA a particularly beneficial education experience for our students and junior scientists.

> ***We intend to continue providing internal resources for programs and facilities, on small to large scales, that have grown from our scientists' creative responses to developments in our field. To enhance this commitment, we will review our technical, program management, and administrative capabilities. SAO internal funds are a strategic asset to be employed for such opportunities.***

Respond to New Opportunities as They Arise

Through the matrix of international, national, and non-government partners already working with us, we anticipate new opportunities in the next decade. Many of these will be substantial and require new resources with national, international, and private partners. We discuss several such programs in various stages of development to illustrate how opportunities arise and evolve:

Theory and Computation

Theory and computation give deep insight into the structure and evolution of the Universe we observe. Theory frequently guides us into new directions which require innovative technologies and lead to powerful and sensitive observational capabilities. Recent Laser Interferometer Gravitational-Wave Observatory (LIGO) discoveries are textbook examples of the special role of theory in astrophysics. The CfA has now and will always need a powerful, intellectually compelling theoretical and computational research program. The present center of this at the CfA is the Institute for Theory and Computation (ITC).

> ***In all of the work outlined in this plan, the importance of theoretical work will inform our choices and focus our efforts on the most compelling questions that will arise.***

Radio and Submillimeter Astronomy

CfA scientist Dr. Sean Andrews leads one of the SMA research programs focused on protoplanetary disks and their significance in seeding planets around stars. He also leads a research program with the Atacama Large Millimeter /submillimeter Array *(ALMA)* whose very high resolution images, e.g. IM Lup (left), show previously unknown structures in protoplanetary disks.

The Submillimeter Array (SMA), commissioned in 2003 and located near the summit of Mauna Kea, Hawaii, is the world's first interferometric telescope at submillimeter wavelengths, contributing to research from star formation to the black hole at the center of the Milky Way. The SMA is a partnership between the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) and SAO.

> ***CfA scientists will continue to compete for observing time on the large international radio telescope known as the Atacama Large Millimeter/Submillimeter Array (ALMA), and continue to exploit the Submillimeter Array (SMA), innovating with forefront science and the rapid adoption of new technologies.***

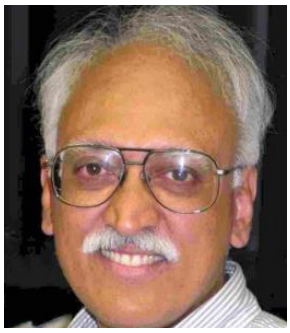
Black Hole Astrophysics: Observations and Theory

On April 10, 2019, the National Science Foundation released the first image of a black hole environment (the center of M87), observed by the *Event Horizon Telescope (EHT)* and shown on the cover of this Plan. The *EHT*, led by CfA scientist Dr. Shep Doeleman, connects radio telescopes across the globe (including the Submillimeter Array, as well as telescopes in Chile, Mexico, Greenland, and at the South Pole) to enable observations of the event horizons of two supermassive black holes, the one at the center of the Milky Way and the one at the center of M87. NSF awarded an *ALMA* 12-meter radio prototype antenna to SAO, providing an opportunity for a critical new northern node for the *EHT* and allowing for unprecedented observations of the northern sky. CfA scientists also lead simultaneous multiwavelength observations of the flaring activity around the Milky Way's black hole using the IRAC infrared camera onboard the *Spitzer* Space Telescope, the *Chandra* X-ray Observatory, and the SMA.

Now known as the Greenland Telescope, the *ALMA* antenna has been relocated to Thule, Greenland. Scientists at the CfA lead this international effort. The Greenland Telescope's first international observing campaign was conducted in April 2017, with technology development and observing campaigns expected to continue for as long as a decade.

Harvard University has launched a new interdisciplinary center called the Black Hole Initiative (BHI), including investigators from the fields of astronomy, physics, mathematics, and philosophy. It is the first center worldwide to focus on the study of black holes. Three CfA scientists are investigators of the Initiative, with the *EHT* playing a prominent role, complemented by theoretical work that informs prospective observational programs.

Harvard Astronomy Professor Ramesh Narayan (right) and SAO scientist Dr. Michael Johnson (left) use computer simulations to compare with images from the Event Horizon Telescope of the black hole at the center of our galaxy.



The CfA will continue to support the Event Horizon Telescope (EHT).

Optical and Infrared Astronomy (not including the GMT)

Our observational program in optical and infrared astronomy is presently centered in southern Arizona at the *MMT Telescope* and in Chile with the twin *Magellan Telescopes,* and in space with the *Infrared Array Camera (IRAC)* onboard *Spitzer*, a NASA great observatory. The *San Pedro Martir Telescope (SPMT)*, to be built by our colleagues in Mexico and located in Baja California, will expand the observing opportunities for our scientists. The *SPMT* will have an optical prescription identical to that of our existing 6.5-m telescopes, *Magellan* and the *MMT*, facilitating the exchange of instruments between them. The skies are exceptionally clear and dark at San Pedro Martir, which will allow more sensitive observations than we can make from the Arizona site. A preliminary design review of the telescope enclosure was held on 11-13 October 2016. A successful preliminary design review of the telescope and optics was held 6-8 November 2017, followed by the beginning of its critical design phase.

NASA's SPHEREx mission, scheduled for launch in 2023, will survey the entire sky with infrared and optical spectroscopic tools, and SAO leads its study of water, ices, and organic molecules in galactic sources.

We are currently working on a Memorandum of Understanding between SAO and the San Pedro Martir Telescope (SPMT).

Solar Physics

As our nearest star, the Sun provides a laboratory for the detailed study of phenomena observed broadly in astrophysics. The CfA has a strong solar physics group involved in solar and heliospheric science and in developing and flying the next generation of solar space telescopes. This group has consistently built the highest resolution solar coronal imagers ever flown.

The CfA solar group also leads the thermal plasma instrument, *SWEAP*, aboard Parker Solar Probe, NASA's mission to "touch" the Sun, planned to extend to 2025. Measuring the solar wind at its birthplace will enable scientists to unravel the mystery of the acceleration of the solar wind as well as explore coronal mass ejections, which are key to understanding Earth-affecting space weather.

Recently the group expanded into infrared airborne instrumentation with the NSF funded AIR-SPEC spectrograph, opening a new wavelength region with observations of the corona during the 2017 and 2019 total eclipses of the Sun.

The Daniel K. Inouye Solar Telescope, a NSF-supported U. S. facility under construction in Hawaii, will offer new opportunities for infrared observations of the Sun.

Jenna Samra, formerly a Harvard Applied Physics graduate student now at the CfA, is seen here on board an NSF Gulfstream V research plane testing the Airborne Infrared Spectrometer (AIR-Spec) ahead of the 2017 eclipse. During the eclipse, AIR-Spec measured four infrared emission features in the solar corona in order to assess their suitability for future observations of the coronal magnetic field. Direct measurements of the coronal magnetic field have significant potential to enhance our understanding of coronal dynamics and improve space weather forecasting models. Space weather research at the CfA has been sponsored by both NSF and NASA. Credit: Cliff Grassmick, dailycamera.com.

> ***We expect our solar physics research program to continue to thrive, and we will seek support for ground-based observations as well as future NASA missions.***

Atmospheric Science

The study of our atmosphere is critically important to us and our fellow inhabitants of the Earth. It also informs our investigations into the atmospheres of extra-solar planets.

TEMPO is a NASA spaceborne instrument mission led by CfA scientist Kelly Chance with the goal of monitoring major air pollutants across the North American continent from geostationary orbit. The CfA is also a partner with the Environmental Defense Fund to develop MethaneSAT, a satellite designed specifically to pinpoint the location and magnitude of methane emissions virtually anywhere on Earth.

We will continue our successful programs, including the HITRAN database, *TEMPO*, and MethaneSAT, and seek new opportunities for growth.

IV. STRENGTHEN THE INTERDISCIPLINARY FRAMEWORK FOR RESEARCH

Astrophysics Advances: Now and Looking Forward

The field of astrophysics is moving rapidly, and the pace of change is accelerating. This is in large part because the complementary sub-fields of theory, observation and technology are increasing-

ly seamless in the implementation of new research directions. Our theorists ask us new compelling – and difficult – questions, stimulating innovative technology developments, targeted precision observational programs, laboratory experiments and new solutions to managing, mining and interpreting the massive data that is necessary for success.

CfA scientists Sagi Ben-Ami, Juliana Garcia-Mejia, and Surangkhana Rukdee are exploring the possibility of developing an extreme high resolution mode for the G-CLEF spectrometer on the GMT, using custom-designed Fabry Perot Interferometer arrays. This work is motivated by the search for biosignatures in the atmospheres of exoplanets.

Exoplanet research is one example of this interdependence.

The initial, gripping discovery phase of extra-solar planet research has matured, and now we look forward to characterizing these planets, examining their atmospheres, and searching for evidence of life. While the NASA *Kepler* mission has demonstrated the ubiquity of planets around other stars, the recently launched Transiting Extrasolar Survey Satellite (*TESS*) will find exoplanets closer to our own solar neighborhood.

The CfA partners with MIT to lead the *TESS* Science Office. Exoplanet science is a strength at the CfA; our scientists are currently involved in every aspect of research on exoplanets, initial discovery, confirmation, and characterization of their atmospheric composition. Determining the composition of exoplanet atmospheres will also require spectroscopic databases in development at the CfA. Bringing the GMT online will bolster our exoplanet work significantly.

Support Laboratory Research, Technology Development, and Data Science.

Laboratory Astrophysics and Astrochemistry

Laboratory investigations have become even more important with the submillimeter capabilities of *ALMA* and the SMA, X-ray spectroscopy from *Hitomi, XRISM,* and possibly *Arcus,* and growing interest in exoplanet atmospheres.

Harvard Professor Karin Öberg directs laboratory and observational investigations into the chemistry that shapes planet formation. Understanding this chemistry, and especially the ice chemistry implicated in the formation of water and organic molecules, informs our theories on the origin of planetary life.

We will continue to support experimental and theoretical investigations at the CfA to help interpret state-of-the-art observations from telescopes.

Technology Development

In addition to recognizing the need for scientific leadership, we also recognize a strong role for SAO's Central Engineering department to provide vital support. Central Engineering is the primary source for the development of scientific instrumentation for the CfA. This robust engineering capability allows us to lead the technology development that our science requires.

Data Science

Astronomy is entering the era of big data, with large survey programs, from *ALMA* to *TESS* to the *LSST* to *EHT*, set to provide a flood of data from which we should be able to learn a great deal about the Universe. Several of our major initiatives, including the GMT and *Lynx*, also require new modes of processing data and making connections across data taken in many different ways. These developments present a rich range of opportunities for CfA scientists, and illustrate the need for the CfA to promote excellence in data science and innovative software development. An example is the ambitious and innovative *Chandra* Source Catalog, now in its second version, which gives access to tabular information and full associated data sets for over 300,000 sources uniformly mined from the public *Chandra* archive.

The CfA hosts multiwavelength data archives, including the *Chandra* archive and the SMA and MMT archives. The CfA also developed and continues to host the NASA- funded Minor Planet Center (MPC), which operates under the auspices of the International Astronomical Union, keeping track of all the minor bodies in the solar system. The CfA has also developed and continues to support a number of atomic and molecular databases used for spectral modeling across the electromagnetic spectrum, including HITRAN,[3] AtomDB,[4] and ATLAS.[5]

The CfA is a key member of the national (USVOA) and international (IVOA) efforts to promote archive and literature interoperability in astronomy, by developing data and software standards. A prime example of the CfA ground-breaking efforts in the data and literature arena is provided by the NASA-funded Astrophysics Data System (ADS), which provides a first-class interface to the astronomy and astrophysics literature, serving the international astronomical community as its primary connection to its literature.

In addition to providing traditional library services, the CfA's Wolbach Library is at the forefront in providing digital services. It has piloted a number of data science trainings, worked with the *American Astronomical Society* on the Unified Astronomy Thesaurus, and has begun to support data curation.

The CfA also fosters research at the frontiers of data science and astronomy, including data analysis using modern astrostatistics, large simulation projects such as *Illustris*, and the development of data mining algorithms. We expect to purchase a large interactive video display to be hosted by the Wolbach Library as a shared resource for data visualization and presentation.

In March 2017, Harvard University announced its new, interdisciplinary Data Science Initiative. CfA staff have expressed interest in how our programs might contribute to and benefit from such an initiative.

3 hitran.org
4 www.atomdb.org
5 kurucz.harvard.edu/programs/atlas12

We will explore different ways that the CfA can provide support for the full variety of astrophysical data initiatives needed by our scientists. We are also exploring the role of libraries in the future of data and code curation.

V. STRENGTHEN THE HARVARD & SMITHSONIAN COLLABORATION

Preserving the nature of the CfA is an important priority in itself. This is best done by establishing an overall direction for our future and remaining well prepared to seize the new opportunities that we are best suited to lead. It is also critical for us to monitor and refine the core collaboration that has been essential to our history and from which our future will develop – the relationship between Harvard University and the Smithsonian Institution and our attention to the things we do so well together.

Modernize the relationship between Harvard and the Smithsonian by implementing a new Memorandum of Understanding.

The highly successful Harvard & Smithsonian relationship provides unique resources to scientists at both institutions. To ensure that the CfA continues to thrive, we plan to build a modern framework for our collaboration. A new Memorandum of Understanding (MOU), signed 23 May 2019, states our aspiration to work together administratively as well as scientifically to support the CfA's mission. The MOU also maintains our commitment to share our scientific facilities. This MOU will provide support from Harvard and the Smithsonian for the mission of the CfA. The next step is to develop a more detailed implementation plan.

The CfA Director's Office is working with Harvard and the Smithsonian to craft an Implementation Plan for the new Memorandum of Understanding.

Move the CfA into a new building.

The CfA presently occupies space at four locations spread across Cambridge and Burlington, MA. The core is located at 60 Garden Street, in structures built in stages between 1847 and 1972. The Smithsonian Office of Facilities, Engineering and Operations (now known as Smithsonian Facilities) examined these facilities in the SAO Existing Conditions Report (2011), where many obvious deficiencies were noted. The CfA can continue to operate in these structures, but the need for a new building is becoming steadily more acute.

Consolidating our staff into a single building will greatly enhance our ability to collaborate scientifically and optimize administrative efficiency and support. The new building should include an auditorium with at least 250 seats, adequate meeting spaces, and sufficient office space to accommodate staff and fellows, and it should meet accessibility standards. A new building could open up access to a full service cafeteria, childcare, and recreational facilities.

Once an Implementation Plan for the new Memorandum of Understanding is in place, we intend to pursue the funding and construction of a new building on or near the Harvard campus, on a time scale of 10-15 years. Meanwhile, we will continue to make renovations to our current facilities as needed to support our scientific mission.

Maintain strong programs to educate and nurture the next generation of astrophysicists.

Harvard University's Department of Astronomy offers a rich program in theoretical, observational, and experimental graduate work leading to the Ph. D. in Astronomy and Astrophysics. The SAO Predoctoral Fellowship Program brings graduate students from other universities to conduct research with CfA scientists. The CfA also hosts about 75 Postdoctoral Fellows in any given year.

With this large cadre of students and postdoctoral fellows, the CfA provides workshops and seminars on an ad hoc basis to enhance their professional development. Demand from students and postdoctoral fellows themselves, as well as national concerns over the preparation of postdoctoral fellows in particular, suggest that we develop a more cohesive approach to professional development.

We will undertake a review of the professional development opportunities offered at the CfA, and consider a more comprehensive effort for selection and evaluation of professional development.

Develop a hiring plan and a strategy that informs it.

Federal scientist Andrea Dupree is shown at the MIKE spectrograph on the Clay Telescope, at Las Campanas, Chile. Dr. Dupree has served on the Federal Scientists Appointment Committee. Based on ideas from the business community, she suggested that three federal positions be opened at a time to optimize the consideration of a broad, diverse pool of candidates.

Recruitment is the responsibility separately of Harvard and of the Smithsonian. We expect that the Harvard Department of Astronomy will work with the Faculty of Arts and Sciences to secure new opportunities to bring new faculty to the CfA. The priorities for new searches will be determined by the needs of the teaching program and by this strategic plan.

Recruitment into Smithsonian federal positions will be responsive to this plan. Most new appointments will be made at the junior level (GS-13), and the searches will be conducted for three positions at a time. Strategic appointments will occasionally be made, usually at more senior levels, at the discretion of the director; it is expected that these will directly support a strategic initiative.

We will increase recruitment activities to ensure strong applicant pools.

Increase diversity, not only of scientists, fellows, and students but also of staff in the administrative and technical departments.

The CfA will expand its initiatives in the development and encouragement of diversity in our field. We will support the excellent work of Harvard's Banneker Institute and Aztlan Institute and contribute to the Future Faculty Leaders program. We will seek additional support for the Latino Program, initially funded through Smithsonian Institution, but now receiving NSF funding. A comprehensive professional development program could address issues specific to diversity. Working with the Gender Equity Committee and the Equity and Inclusion Journal Club, the CfA will conduct regular, periodic reviews of the workplace "climate." The CfA will also review the diversity of the administrative and technical departments.

The CfA will foster a workplace climate that is productive for all of its members.

VI. CONCLUSION

We intend this plan as a vision for our broad audiences to discover, or re-discover, the intersection of their interests with the future of the CfA.

To the leadership of our parent institutions, we affirm the strength and vibrancy of each of our Observatories. Our collaboration is working well, and we can enhance it through the actions set out in the plan. We will continue to deploy our collaborative skills in all that we do in the broad field of astrophysics research and education.

To our many visitors, most of whom are "virtual visitors," we commit ourselves to advancing their engagement with our work and to increasing their understanding of the Universe we inhabit together.

To our funding agencies, we will maintain our distinctive competencies for key agency priorities as well as skilled management of our – and their – resources. Future work will be based on our intellectual leadership and our competitive preparedness in mission development, program management and operational excellence.

To our friends and contributors, we show evidence of the new programs their support has made real. We also hope that they are inspired to assist our growth and focus in the next decade.

To the media, our message is direct: the people of the CfA make science news and stand ready and able to tell compelling science stories to the world.

To those who are considering a professional move to the CfA, we invite their interest and encourage them to engage with us and our large and intellectually diverse community of scientists, students, postdoctoral fellows, administrators, and technical staff members.

Finally, to those who are already members of our CfA community, we present this plan as affirmation of our deep gratitude for their talents and work.