Training of Instrumentalists and Development of New Technologies on SOFIA

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Introduction

The Astronomy and Astrophysics 2010 Decadal Survey (Astro2010)[1] Committee has requested white papers related to the State of the Profession[2]. In response, this paper is submitted to emphasize the potential of the Stratospheric Observatory for Infrared Astronomy (SOFIA) to contribute to the training of instrumentalists and observers, and to related technology developments. This potential goes beyond the primary mission of SOFIA, which is to carry out unique, high priority astronomical research.

SOFIA is a Boeing 747SP aircraft with a 2.5 meter telescope[3]. It will enable astronomical observations anywhere, any time, and at most wavelengths between 0.3 µm and 1.6 mm not accessible from ground-based observatories. These attributes, accruing from SOFIA's mobility and flight altitude, guarantee a wealth of scientific return. Its instrument teams (nine in the first generation) and guest investigators will do suborbital astronomy in a shirt-sleeve environment. The project will invest $10M per year in science instrument development over a lifetime of 20 years. This, frequent flight opportunities, and operation that enables rapid changes of science instruments and hands-on in-flight access to the instruments, assure a unique and extensive potential - both for training young instrumentalists and for encouraging and deploying nascent technologies. Novel instruments covering optical, infrared, and submillimeter bands can be developed for and tested on SOFIA by their developers (including apprentices) for their own and guests' observations, to validate technologies and maximize observational effectiveness.

Although SOFIA's breadth in wavelength coverage, instrument capability, and observing flexibility guarantee that it will make major contributions in important areas of astrophysics, SOFIA's contributions to science are not the subject of this current white paper.

Airborne Astronomy Heritage

SOFIA will promote the advancement of needed technologies and grow the competencies of the next generation with relevant instrumentation. Our confidence in this potential is based on experience from the airborne astronomy program that operated at NASA Ames Research Center from 1965 to 1995, and in particular on the 21 years of achievement of the Kuiper Airborne Observatory (KAO). Its many accomplishments – for example early evidence for hot stars and a black hole at the Galactic Center (based on far-infrared spectroscopic observations made when based in Honolulu and Christchurch, New Zealand), and discovery of the rings of Uranus (based on optical observations of a stellar occultation made when based in Perth, Australia) – attest to the effectiveness of the KAO *modus operandi*.

A primary factor in the scientific success of the KAO was the vigorous and productive science instrument-development program it spawned in the science community. Sixteen of the instruments existing in 1995, listed in Table 1, exhibit the wide range of technologies made available by the instrument teams *for observations not possible from ground-based sites.*

Table 1. Kuiper Airborne Observatory Focal Plane Instruments Existing in 1995

Principal Investigator/ Affiliation	Instrument Type	Wavelength Range (μm)	Spectral/Spatial Channels	Spectral Resolution
A. Betz / U. Colorado	Heterodyne Spectrometer	60-400	512/1	δν=3 MHz
J. Bregman / NASA Ames & D. Rank / Lick Observatory	Photometer/Camera	2-5, 6-13	1/128x128	Various (Filters)
E. Dunham / NASA Ames	High Speed CCD Photometer	0.3-1.1	1/2048x2048	Various (Filters)
E. Erickson / NASA Ames	Echelle Spectrometer	16-210	32/1	λ/δλ ~ 1000-5000
D. Harper / Yerkes Observatory	Photometer/Camera	30-500	1/8x8	λ/δλ ~ 2-10
P. Harvey / UT Austin	High Angular Resolution Camera	40-200	1/2x10	λ/δλ ~ 20-100
T. Herter / Cornell U.	Grating Spectrometer	5-36	128/128	λ/δλ ~ 100-9000
R. Hildebrand / U. Chicago	Polarimeter	100	1/6x6	λ/δλ ~ 2.5
H. Moseley / NASA GSFC	Grating Spectrometer	16-150	48/1	λ/δλ ~ 35-200
H. Larson / U. Arizona	Michelson Interferometer	1-5	1	λ/δλ ~ 1000-300,000
H. Röser / DLR Berlin (DE)	Heterodyne Spectrometer	100-400	1400/2	δν ~ 1 MHz
R. Russell / Aerospace Corp.	Prism Spectrometer	2.9-13.5	58/1 & 58/1	λ/δλ ~ 25-120
G. Stacey / Cornell U.	Imaging Fabry-Perot Spectrometer	18-42	1/128x128	λ/δλ ~ 35-100
C. Townes / UC Berkeley & R. Genzel / MPE Garching, DE	Imaging Fabry-Perot Spectrometer	40-200	1/5x5	λ/δλ ~ 3000-300,000
F. Witteborn / NASA Ames	Grating Spectrometer	5-28	120/1	λ/δλ ~ 300-1000
J. Zmuidzinas / CalTech	SIS Heterodyne Spectrometer	370-600	160/1	δν ~ 0.6, 3.0 MHz

About 50 specialized science instruments encompassing a wide variety of technologies and capabilities were developed and used by 33 different instrument teams on the KAO during its lifetime. Instrument teams were led by scientists from university, government, and industry laboratories, both U.S. and foreign. They developed the instruments at their home institutions, installed them on the telescope, operated them in flight, and analyzed and published the data. Instrument upgrades were typically made between flight series. The science instruments usually employed the most recently developed or high-tech equipment on the observatory. Probably because they were operated by their developers for their own or for guest investigations, the instruments were actually more reliable than either the aircraft or the telescope system.

A related important if intangible factor in the success of the KAO was the entrepreneurial and enthusiastic spirit it fostered in the investigator teams. Participants were excited by the opportunity – unique in the annals of modern astronomy – to personally prepare for and perform suborbital observations from anywhere on the globe.

The value of this program to the community is evinced in part by the recognitions received by its participants. Some of the awards earned by astronomers experienced with airborne astronomical instrumentation are listed in Table 2. Nine of the sixteen awardees were airborne instrument team leaders. These awards, while not necessarily related directly to research done in the airborne program, demonstrate (1) its appeal for creative application of advanced technologies, and (2) its excellent opportunities for mentoring and developing researchers' skills in observational astronomy and instrumentation. That a majority (four out of seven) of the American Astronomical Society Weber Awards for instrumentation have gone to researchers with extensive airborne astronomy experience attests not only to the effectiveness of the program in fostering opportunities for new instrumentation developments by individual teams, but also to the potential for rapidly advancing infrared and submillimeter technologies.

Table 2. Some Awards Received by Astronomers with Airborne Experience

AAS Pierce Prize for outstanding achievement in observational astronomy over the past five years for researchers under 36 years old	Eric E. Becklin#, Doyal A. Harper*#, Reinhard Genzel#, Harriet L. Dinerstein, Kristen Sellgren*
AAS Cannon Award for outstanding research and promise for future research by a woman within five years of receiving her Ph.D.	Harriet L. Dinerstein, Suzanne Madden
AAS Weber Award for Astronomical Instrumentation leading to advances in astronomy	Frank J. Low#, Thomas G. Phillips#, Harvey Moseley*#, James R. Houck#
ASP Bruce Gold Medal for a lifetime of outstanding research in astronomy	Martin Harwit#, Frank J. Low#
ASP Muhlmann Award for innovative advances in astronomical instrumentation	John H. Lacy, Michael Skrutskie
Nobel Prize for fundamental work in quantum electronics	Charles H. Townes#
MacArthur Foundation Award for astrophysics	John E. Carlstrom
Pawsey Medal (AU) for excellence in experimental physics	John W. V. Storey

AAS: American Astronomical Society; ASP: Astronomical Society of the Pacific
* indicates Ph.D. thesis included data from airborne observations.
\# indicates team leader for development of airborne science instrument(s)

Besides the astronomers recognized in Table 2, roughly 200 others – including many graduate students and post-doctoral researchers – participated in the development of instrumentation for airborne observations. The table in the appendix lists some of the scientists whose careers included experience with airborne instrumentation and observations, and who have gone on to make significant contributions in ground- and/or space-based astronomy, including leadership roles in the astronomical community. No matter their subsequent activities, nearly all appreciate and can vouch for the value of their experiences in developing and using airborne instruments. We may expect a substantially larger long-term benefit to the community from the increased instrumentation activity that SOFIA will support.

We recognize that modern focal plane instruments are more complex, expensive, and require longer development periods than those of the KAO era. This is true in all astronomy disciplines. However, the basic merits of SOFIA relative to other facilities for training of personnel and implementation of technology are still valid.

The Need for Training Instrumentalists

The development of technically skilled individuals is a national priority. This is made clear in the “America COMPETES Act”[4], a bipartisan congressional response to recommendations contained in the National Academies’ “Rising Above the Gathering Storm” report and the Council on Competitiveness’ “Innovate America” report. These documents emphasize the need for maintaining and improving innovation in the United States in the 21st Century.

The need is not new. NASA supports astronomy based on the mandate in its charter, the National Aeronautics and Space Act[5], that lists as the agency’s first objective: “The expansion of human knowledge of the Earth and of phenomena in the atmosphere and space.” Current NASA programs support this mandate, as shown for example by the explicit objective of the Advanced Planning & Integration Office Roadmap[6] “to advance the scientific and technological capabilities of the nation”.

To accomplish these objectives requires talented and highly trained personnel. The 2006 National Academy of Science Space Studies Board report *Building a Better NASA Workforce*[7] cites earlier studies of space science and engineering as well as opinions of current experts, to conclude “…there is ultimately no substitute for hands-on training.” This principle extends from project managers through systems engineers to specialists skilled with sophisticated astronomical instrumentation and observing techniques, both within and outside of NASA. Explicit technology and training needs for SOFIA and related future space missions are described in the "2008 Community Plan for Far Infrared/Submillimeter Space Astronomy"[8].

The Need for Infrared/Submillimeter Instrumentation

Community workshops and studies over the past decade have assessed technology progress and identified and prioritized future needs and the corresponding potential science return. For infrared and submillimeter astronomical research, the most comprehensive is *Detector Needs for Long Wavelength Astrophysics*, A NASA Report by the Infrared, Submillimeter and Millimeter Detector Working Group (ISMDWG, 2002)[9]. Proceedings of the SOFIA 20/20 Vision Workshop (2007)[5] describe subsequent progress and current relevance of the ISMDWG report.

Quotes below are from the executive summary of the latter, with items particularly relevant to SOFIA highlighted in italics:

*"Observations at infrared, submillimeter, and millimeter wavelengths will be essential for addressing many of the key questions in astrophysics***.** Because of the very wide wavelength coverage, a variety of detector types will be required to satisfy these needs. To enable and to take full advantage of the opportunities presented by the future mission concepts under consideration, *a significant and diverse effort in developing detector technologies will be needed.*

"The ISMDWG finds that the development of very large (10^3 – 10^4 pixels) arrays of direct detectors for far infrared to millimeter wavelengths to be the most important need…. *with the emphasis on producing complete systems.*

"As detector systems become larger, more complex, and more expensive, the available mechanisms for supporting development from proof of concept to flight worthy technology are limited. We encourage NASA to develop the resources to support this type of engineering. As part of this finding, *we stress the importance of maintaining key infrastructure elements in the research community*… For coherent systems, the greatest need is improvement in sensitivity between 1 – 3 THz (300 – 100 µm). Additionally, *development in other system components [such as readout technologies and] local oscillators will be needed.* The development of arrays of coherent receivers will greatly increase mapping speed…

"Continuity and stability of funding is essential to insuring the availability of detectors for future missions."

Infrared technology is improving rapidly. All of these recommendations are served by the airborne astronomy program, and the test-bed opportunities provided by SOFIA.

The Potential of SOFIA

Training: SOFIA will offer the *unique* capability for instrument builders and scientists to make hands-on, real time, astronomical observations with cutting edge technologies at wavelengths obscured from the ground. As studies cited above have found, this is the most effective approach to teaching skills needed for the development and validation of the sophisticated, high technology instrumentation systems that will be required for future space-based observatories.

Valuable lessons and skills for space-mission instrument preparation are taught in the development, deployment and upgrading of science instruments. For and airborne observatory, this is a considerably more structured process than for an average ground based instrument, but is considerably less onerous than that for space instrumentation. While operation on an aircraft makes personnel safety a critical issue, the minutiae of space mission assurance concerns are relatively minimal. Close coordination of all activities – flight planning, instrument airworthiness approval, contingency planning, instrument servicing and maintenance, etc. – is required. Airborne instrument teams must learn to work with a wider range of concerns and staff than ground-based instrument teams.

The airborne instrumentation culture can serve as an effective transitional step between the environments of ground-based and space-based instrumentation.

Instrumentation: SOFIA's ongoing investment in new focal plane instrumentation will provide some of the needed resources and continuity for the development and verification of complete instrument systems that have been recommended[9]. As reported in the 20/20 Vision Proceedings[10] "For a significant period of time (after Herschel and before a large space mission like SPICA or SAFIR), SOFIA will be the only [routine] access to much of the key far-infrared and sub-millimeter wavelength range." Balloon-borne platforms can also provide testing of infrared and submillimeter instrumentation, to provide observations such as surveys of the Milky Way and nearby galaxies that can be followed up by SOFIA at higher angular resolution. Both SOFIA and balloons will be valuable for developing instruments incorporating advanced technologies, particularly at Technical Readiness Levels[11] 4 and above. Such test-beds will be efficient and productive means to obtaining the experience needed to reduce risks for the next generation of space observatories.

The needed detector/receiver technologies are still in a relatively primitive state because they have received minimal military or commercial development support. Thus these technologies are appropriate for development at university and government laboratories, as will be encouraged by the availability of and support from SOFIA.

The larger format direct-detection arrays needed for far infrared wavelengths will enable, among numerous other investigations, an efficient census of young stellar objects in nearby (extended) molecular clouds, e.g. Taurus and Ophiuchus, to produce a reasonably complete protostellar classification. As an example, SOFIA's first generation far infrared imager, HAWC[3], currently has a 384 element bolometer detector array. The optics in this camera provide an unvignetted field of view of 6.3 arc minutes diameter. To Nyquist sample this area at a wavelength of 50 µm would require an upgrade to an array of ~25,000 pixels, which would increase the mapping speed by a factor ~60. Such arrays are now foreseeable. Clearly the investment in this technology would be well justified in terms of cost effectiveness on SOFIA, and much more so on future NASA missions. SOFIA can help to bridge the gap to such technology developments.

Similarly, an increase in sensitivity of submillimeter heterodyne receivers would be an extremely valuable addition to NASA's astronomy capabilities. The receivers currently operating at 1-3 THz (300-100 microns) are factors ~10-20 above the fundamental quantum noise limit theoretically achievable. Higher sensitivity could, for example, enable measurement of molecular transitions in cold, prestellar cores to characterize the chemistry affecting the evolution of the earliest stages of star formation. Again, SOFIA offers a test-bed in which cutting edge systems can be exercised while doing high priority science.

In addition to these potential applications, SOFIA will be able to host other significant instrument capabilities[10]. Among these are infrared polarimetry, not available from Herschel or foreseen on JWST, and spectral imaging. Both of these would take advantage of the large format direct detector arrays. In addition, arrays of terahertz heterodyne receivers would vastly improve mapping speeds for high resolution (~1 km/sec) spectroscopy. The related technologies also required to build and evaluate practical, complete instruments will of course be part of these developments.

Complementarity: For science, and for development of instrumentalists and novel instrumentation/technology, SOFIA's contributions will complement those of ground-based, other suborbital, and space-borne telescopes.

Scientific Complementarity: Scientifically, SOFIA's attributes of world-wide mobility and access to most infrared/submillimeter wavelengths unavailable from the ground assure that airborne and ground-based astronomy are complementary. SOFIA's mobility and flexible scheduling allow rapid deployment for observing ephemeral events (comets, eclipses, occultations, etc) that often escape observations by telescopes in space.

Airborne astronomy is also highly complementary to the infrared and submilimeter *science* capabilities enabled by the other suborbital platforms: sounding rockets and balloons. Balloons and rockets reach higher altitudes than SOFIA and thus offer even higher atmospheric transparency. The long duration balloon program can provide months of time-on-source, which is particularly valuable for surveys. Infrared and submillimeter observations from balloons are thus very valuable scientifically, and can provide results to guide follow-on observations by SOFIA. However, rockets and balloons typically have relatively infrequent launch opportunities and single-purpose science instruments. The observing programs are usually highly focused, and so typically do not support guest investigators.

In contrast, SOFIA will function as a general purpose observatory. It will fly often during the year, offer access to the entire sky, and provide prompt response for observation of targets of opportunity. Its operation and large instrument complement are designed to support guest investigators. Close involvement of astronomers with the science instrument and the flexibility of the platform allows for real time decisions on observational strategies and in dealing with unforeseen contingencies. Clearly SOFIA's science paradigm complements that of balloons and rockets.

Scientific complementarity of SOFIA and space astronomy facilities is assured by NASA's requirement of limited overlap in the capabilities of the concurrent missions it sponsors.

Instrumentation and Training Complementarity: Instrumentation development and personnel training for systems operating at wavelengths inaccessible from the ground would of course not be appropriate for ground-based observatories, assuring no overlap with SOFIA. Of course ground-based observatories provide excellent and extensive opportunities for developing talent and instrumentation in their available spectral ranges, and in that sense are akin to SOFIA.

Relative to space-based and other suborbital facilities, SOFIA will offer the *unique* capability of literal hands-on access to its instruments during operation, as well as frequent opportunities for instrument servicing (*e.g.*, cryogen refill), diagnostics, maintenance, upgrades, and exchange. It will afford ample mass, electrical power, and computational infrastructure for the instruments on board. Its instruments and personnel will operate in a shirt-sleeve environment. The access to the instruments removes reliance on telemetry for command and data transfer, and minimizes dependence on remote controlled actuators for adjusting the instrument configuration. These are ideal conditions for training purposes and instrument development focused on the basic performance of the instrument, and assure as well reduced development cost and increased reliability for successful data acquisition. Thus SOFIA will provide a rich environment for training and creative application of new technology developments, while playing a pivotal role in expanding our understanding of the universe.

Sociologically airborne, balloon and rocket facilities are closely related. Balloons and rockets fill a valuable role for instrument and personnel development for a broader community than SOFIA, namely one that includes ultraviolet, x-ray, gamma ray, and cosmic ray observational disciplines. However, the instruments must tolerate the low pressures and temperatures at high altitudes, and must be remotely controlled. Weight limitations on balloons make it difficult to fly telescopes with apertures as large as SOFIA's, thereby limiting their point source sensitivity and angular resolution. Instrument support infrastructure (for weight, power, and data processing) is more restrictive. Solving these problems is of value in gaining experience, but must be done in addition to dealing with the intrinsic issues associated with the instrument itself. Reliability of payload recovery is also concern for balloon and rocket astronomy, especially with regard to high-cost components. So, while there are similarities among the suborbital facilities, SOFIA remains quite complementary to balloon and rocket programs.

As regards space-borne telescopes, the above discussion makes clear the complementarity between them and SOFIA, which is due largely to the access to the instruments, reflight frequency, platform infrastructure, *etc* provided by SOFIA.

Thus SOFIA can be aptly described as a ground-based observatory that does suborbital astronomy.

Conclusion

Significant, diverse efforts and skilled individuals will be required to develop detector and instrument technologies identified to meet the needs of future NASA astrophysics missions. SOFIA will provide an excellent stimulus, test-bed, and training ground for this work. With over 100 flights anticipated annually throughout its expected 20 year lifetime, SOFIA will afford frequent and unparalleled opportunities for advancing instrument capabilities and personnel competencies in the field of infrared and submillimeter astronomy.

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Acronyms

Acronyms used in this paper are given in Table 3.

Table 3. Acronyms

ALMA	Atacama Large Millimeter Array	KAO	Kuiper Airborne Observatory
AU	Australia	Kepler	Satellite to Search for Earthlike Planets
CARA	Center for Astrophysics Research in Antarctica	LIGO	Laser Interferometer Gravitational Wave Observatory
CASIMIR	CAltech Submillimeter Interstellar Medium Investigations Receiver	MIRS	Mid Infrared Spectrometer
		MPE	Max Planck Institute for Extraterrestrial Physics
CEA	Atomic Energy Commission (FR)	MPIA	Max Planck Institute for Astronomy
CSO	Caltech Submillimeter Observatory	NICMOS	Near Infrared Camera and Multi Object Spectrometer
CMBR	Cosmic Microwave Background		
DE	Germany	NL	Netherlands
DLR	German Aerospace Center	PACS	Photodetector Array Camera and Spectrometer
ESO	European Southern Observatory	PI	Principal Investigator
FIFI LS	Field Imaging Far-Infrared Line Spectrometer	PYTHON	CMBR Submillimeter Polarimeter
		RIT	Rochester Institute of Technology
FORCAST	Faint Object InfraRed CAmera for the SOFIA Telescope	SIS	Superconductor-Insulator-Superconductor
		SAFARI	SpicA FAR-infrared Instrument
FR	France	SAFIR	Single Aperture Far Infrared Observatory
HAWC	High-resolution Airborne Wideband Camera	SAFIRE	Submillimeter And Far InfraRed Experiment
		SAO	Smithsonian Astrophysical Observatory
HIFI	Heterodyne Instrument for the Far Infrared	SHARC	Submillimetre High-Angular Resolution Camera
		SHARP	SHARC CII Polarimeter
HIPO	High speed Imaging Photometer for Occultations	SOFIA	Stratospheric Observatory for Infrared Astronomy
		SPARO	Submillimeter Polarimeter for Antarctic Remote Observing
HST	Hubble Space Telescope		
IRAC	Infrared Array Camera	SPICA	Space Infrared Telescope for Cosmology and Astrophysics (JP)
IRAS	Infrared Astronomy Satellite		
IRS	Infrared Spectrometer	SPIRE	Spectral and Photometric Imaging Receiver
IRTF	Infrared Telescope Facility	Spitzer	Space Infrared Telescope
IRTS	Infrared Telescope in Space (JP)	SRON	Netherlands Institute for Space Research
ISMDWG	Infrared Submillimeter Detector Working Group	STScI	Space Telescope Science Institute
		SWAS	Submillimeter Wave Astronomy Satellite
ISO	Infrared Space Observatory	SWS	Short Wavelength Spectrometer
JWST	James Webb Space Telescope	USRA	Universities Space Research Association
JP	Japan	WISE	Wide-Field Infrared Survey Explorer

Appendix

Some Participants in Airborne Instrument Developments and Some Subsequent Contributions

Scientist	Current Affiliation	Notable Activities
Eric Becklin*	UCLA/USRA	SOFIA Chief Scientist; former IRTF Director, HST/NICMOS Instrument Team
Steve Beckwith*	U. California.	Vice President for Research; former Director, STScI, MPIA
John Carlstrom	U. Chicago	Director, Kavli Institute for Cosmological Physics
Jackie Davidson*	U. Western Australia	Former SOFIA Project Scientist
Jessie Dotson	NASA ARC	SOFIA/HAWC Team, Kepler Science Planning Team
Darren Dowell	Caltech	SHARC photometer for CSO
Mark Dragovan	JPL/Caltech	CARA /YTHON CMBR Instrument Team
Ted Dunham*	Lowell Observatory	PI SOFIA/HIPO; Kepler camera feasibility team
Jim Elliot*	MIT	SOFIA/HIPO Team
Ed Erickson*	NASA ARC, retired	Original SOFIA Project Scientist for NASA; HST/NICMOS Instrument Team
Ian Gatley	RIT	Dean of Science
Reinhard Genzel*	MPE, Garching DE	Director, MPE; Herschel /PACS Team
Thijs de Graauw*	SRON, Groningen NL	Director, ALMA; PI Herschel/HI-FI, ISO/SWS
Matt Greenhouse	NASA GSFC	Project Scientist for JWST Science Instrument Payload
D. A. Harper*	U. Chicago	PI SOFIA/HAWC; former director CARA
Paul Harvey*	University of Texas	Mission Scientist, Herschel
Martin Harwit*	Cornell U., Emeritus	Mission Scientist, Herschel and ISO; SWAS Team
Terry Herter*	Cornell University	PI SOFIA/FORCAST; Spitzer support
Roger Hildebrand*	U. Chicago, retired	Former Astronomy and Astrophysics Department Chair
Jim Houck*	Cornell University	PI Spitzer/IRS; IRAS Co-I
Dan Lester	University of Texas	PI for SAFIR Vision Mission Study
Frank Low*	Infrared Laboratories	IRAS Co-I, Initial Spitzer Facility Scientist
Suzanne Madden	CEA Saclay FR	Herschel/SPIRE, PACS and SPICA/SAFARI instrument teams
Gary Melnick	Harvard SAO	PI SWAS, Deputy PI Spitzer/IRAC
Alan Moorwood*	ESO	ESO Instrument Program Director
Harvey Moseley*	NASA GSFC	PI SOFIA/SAFIRE; detector systems Chandra, JWST
Giles Novak	Northwestern U.	Polarimeters SPARO for South Pole; SHARP for CSO
Tom Phillips*	Caltech	Director, CSO; U.S. team leader on Herschel
Judy Pipher*	U. Rochester, retired	Spitzer/IRAC Team
Albrecht Poglitsch	MPE, Garching DE	PI SOFIA/FIFI-LS and Herschel PACS
Tom Roellig	NASA ARC	SOFIA Project Scientist for NASA; Spitzer Facility Scientist, IRTS/MIRS (JP) instrument team
Hans-Peter Roeser*	U. Stuttgart DE	Managing Director, Institute for Space Systems
Michael Skrutskie	U. Virginia	PI, Two Micron All Sky Survey
Tom Soifer	Caltech	Director, Spitzer Science Center
Alan Tokunaga	NASA IRTF Hawaii	Director, NASA IRTF
Charles Townes*	UC Berkeley, retired	PI, Ground-based Infrared Spatial Interferometer
Mike Werner*	JPL/Caltech	Project Scientist Spitzer
Stan Whitcomb	LIGO/Caltech	Chief Scientist, LIGO
Fred Witteborn*	NASA ARC, retired	Original SIRTF (Spitzer) Project Scientist; Kepler camera feasibility team
Ned Wright	UCLA	PI WISE
Jonas Zmuidzinas*	Caltech	PI SOFIA/CASIMIR; Herschel/HIFI instrument team

* indicates science instrument team leader on the KAO and/or Learjet Observatory