SOFIA and Herschel

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Executive summary

Within the scientific communities of the countries involved, SOFIA and Herschel are two highly recommended infrared and sub-millimeter missions under development that plan to address fundamental questions in astrophysics:[1]

> "In the life cycle of stars, how are stars and planetary systems formed and how do they die and return their ashes to the interstellar medium?",
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> "What is the molecular makeup of the interstellar medium and how does that relate to the origin of life?",
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> "How have galaxies evolved over time?", and
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> "What powers the nuclei of our own and other galaxies?".

The respective instrument suites of these two missions have been optimized to address different aspects of these questions. SOFIA has a large and versatile instrument complement that covers infrared and sub-millimeter wavelengths at a wide range of spectral resolutions, and is therefore capable of studying astrophysical questions from many different perspectives in a wide range of objects. Herschel's fewer instruments, covering a more limited range of far-infrared and sub-millimeter wavelengths, are designed to take full advantage of a cold and stable space-based platform and are geared towards large scale unbiased photometric surveys of the high z universe as well as high spectral resolution surveys of the molecular universe, and studies of astrophysically important species like water that are heavily masked by attenuation in the earth's atmosphere.

While each mission is well suited to address its own scientific goals, the differences in instruments aboard SOFIA and Herschel give rise to great complementarity of astronomical investigations. Indeed, a strategic alliance of these two missions carries in it the promise of a great scientific synergy. While Herschel will focus on charting for the

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[1] SOFIA and Herschel are highly recommended by the National Academy of Sciences decadal committees that advise NASA and the Astrophysics Working Group and the Space Science Advisory Committee and the Science Programme Committee that advises ESA, respectively.

first time the hardly-known far-IR and sub-millimeter universe, SOFIA is well suited to mine this wealth of new discoveries with a versatile instrument complement to determine the physical characteristics of the newly discovered objects and their role in the universe and its evolution.

In addition, while Herschel's instrumentation is limited to wavelengths longwards of ~60 μm, SOFIA will cover the full infrared range from 0.35 to 650 μm. Once Spitzer runs out of helium (late 2008/early 2009), SOFIA is the only observatory that can complement far-infrared and sub-millimeter studies in the mid-infrared and can probe the full spectral energy distribution of astronomical objects and can spectroscopically explore important gas and dust tracers at shorter wavelengths. In addition, SOFIA will provide unique high spectral resolution capabilities from 5 to 28, 100 to 120 and around 60 μm – covering the fundamental ro-vibrational transitions of all molecules and the fine-structure transitions of many key atoms and ions – that are outside of Herschel's range. Note that Spitzer has only low spectral resolution capabilities from ~5-40 μm.

Finally, SOFIA has a designed lifetime of 20 years and can continue to explore the far-infrared and sub-millimeter sky long after Herschel runs out of helium, nominally 3 years after launch. This long lifetime also allows SOFIA to fly an ever-improving array of instruments. Indeed, SOFIA's vigorous technology and instrument development program is set up to take full advantage of the rapid advances in infrared and sub-millimeter instrumentation that can be expected over the coming decade.

Introduction

This white paper focuses on the issue of complementarity and synergy between the two infrared and sub-millimeter missions, SOFIA and Herschel. The full scientific rationals for these two missions have been addressed elsewhere and that will not be repeated here. Nevertheless, for completeness, we start of with a brief summary of the SOFIA and Herschel missions and their instrument complements. Details can be found through the SOFIA (http://www.sofia.usra.edu/) and Herschel (http://sci.esa.int/home/herschel) websites.

SOFIA

The Stratospheric Observatory for Infrared Astronomy, SOFIA, will place a 2.5 meter telescope – similar in size to Hubble's telescope – on board a modified Boeing 747 SP. This observatory will fly above most of the atmospheric water vapor, which blocks ground-based observations throughout much of the infrared and sub-millimeter.

As a partnership between the U.S. and German space agencies (NASA and DLR), SOFIA's first-generation instrument complement includes 7 U.S. instruments and 2 German instruments:

- HIPO (High-speed Imaging Photometer for Occultations) – an optical dual channel, high speed CCD imager
- FLITECAM (First Light Infrared Test Camera) – a near-infrared imager with spectroscopic capabilities
- FORCAST (Faint Object Infrared Camera for the SOFIA telescope) – a mid-infrared dual channel imager with narrow-band filters
- GREAT (German Receiver for Astronomy at Terahertz Frequencies) – a far-infrared heterodyne spectrometer of high spectral resolution
- FIFI-ls (Field Imaging Far-Infrared Line Spectrometer) – a far-infrared integral field spectrometer of moderate spectral resolution
- CASIMIR (CalTech Submillimeter Interstellar Medium Investigations Receiver) – a submillimeter heterodyne spectrometer of high spectral resolution
- HAWC (High-resolution Airborne Wideband Camera) – a far-infrared narrow band imager
- EXES (Echelon-Cross-Echelle Spectrograph) – a mid-infrared grating spectrometer of high spectral resolution
- SAFIRE (Submillimeter and Far-Infrared Experiment) – a fabry-perot spectrometer of moderate spectral resolution.

The unique discovery space of SOFIA spans an extremely broad spectral range (0.35 to 650 microns) that can be investigated with a wide variety of spectral resolutions tailored to different applications from low-resolution observations of continuum dust emission

(□/□□ ~few), to solid-state emission/absorption features (□/□□ ~1000), to velocity-resolved gas-phase emission lines(□/□□~10^5). The spectral characteristics of SOFIA's first-generation instruments are illustrated in Figure 1 and summarized in Appendix 1. Second generation instruments for SOFIA are funded under the observatory's operations phase.

SOFIA's suite of first-generation instruments will probe the dust/gas energy and mass budget, the physical conditions in the emitting/absorbing dust and gas, the gas dynamics, and the elemental and molecular composition in a wide range of objects: Solar system objects, circumstellar disks, evolved stars (such as red giants and supergiants, planetary nebulae, and supernova remnants), molecular clouds and star forming regions, the ISM of the Milky Way and other galaxies, galactic nuclei, starbursts, AGN, etc.. Currently

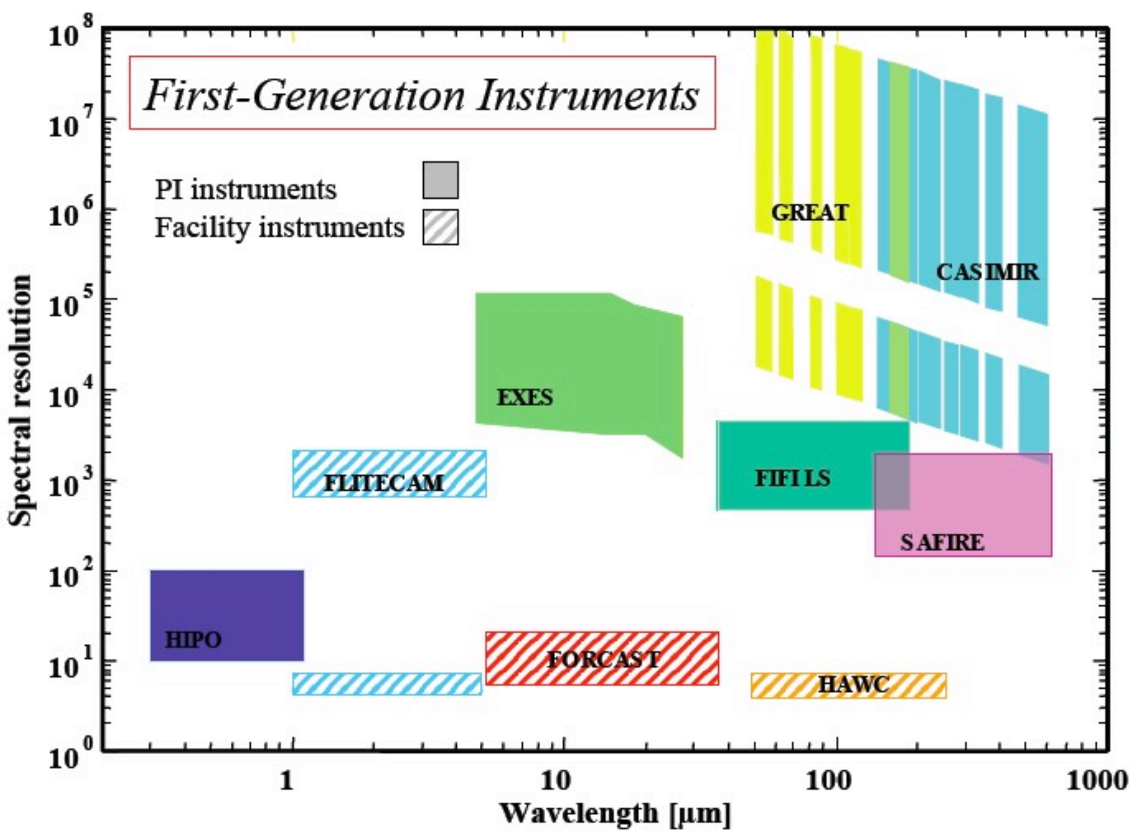

Figure 1: SOFIA's discovery space: The first generation instruments on SOFIA cover the full infrared and sub-millimeter wavelength range and span a wide range in spectral resolution. For further detail see Appendix 1.

funded instruments will enable science programs ranging from the composition and pressure distribution of planetary atmospheres, tracing transits of Kuiper belt objects and extrasolar planets, studying the chemistry of the cold interstellar medium, measuring the physical conditions, chemical composition, and dynamics of star forming regions, determining the characteristics of the interstellar polycyclic aromatic hydrocarbon "family", the structure of debris disks around nearby stars, the characteristics of cirrus clouds in the interstellar medium, the dynamics of the galactic center, and supernova nucleosynthesis.

As a sub-orbital observatory, SOFIA is designed for a 20-year operational lifetime. With funding during normal operations, the SOFIA instrument suite will evolve and adapt through upgrades to existing instruments and a robust development program for new instruments that can take full advantage of technical advances at the earliest possible date. These will be vital to probe questions emerging from the legacy of the Spitzer and Herschel data sets. The ability to field novel technologies on the time scales short compared to space flight missions is a major strength of the SOFIA program and will be discussed below in section E.

Herschel

Herschel has a radiatively cooled 3.5-m telescope and a science payload complement of three instruments housed inside a superfluid helium cryostat with a cryogenic lifetime of approximately 3 years. The launch of Herschel is scheduled for early 2008, on the same vehicle as the Planck mission. Both missions will orbit independently around the second Earth-Sun Lagrange point. NASA is a minor partner in the Herschel Mission, with US participants contributing to the mission through mission-enabling instrument technology, user software development, and through sponsorship of the NASA Herschel Science Center at IPAC (the NHSC).

Herschel's three instruments are:

- PACS (Photodetector Array Camera and Spectrometer) - an imaging photometer and medium spectral resolution grating spectrometer
- HIFI (Heterodyne Instrument for the Far Infrared), a very high spectral resolution heterodyne spectrometer
- SPIRE (Spectral and Photometric Imaging Receiver) - an imaging photometer and an imaging Fourier transform spectrometer

Herschel will perform photometry and spectroscopy in approximately the 57-670 μm range. The spectral characteristics of these three instruments are compared with those of SOFIA in figure 2. Herschel is designed to observe the 'cool universe'; it has the potential of discovering the earliest epoch proto-galaxies, revealing cosmologically evolving AGN/starburst symbiosis, and unraveling the mechanisms governing the formation of stars and planetary systems, such as our own. Herschel will also investigate the chemistry of our galaxy and the molecular chemistry of planetary and cometary atmospheres in the solar system.

Because there is no complete census of the sub-millimeter sky, Herschel is often referred to as being "its own precursor mission" and a substantial fraction (~2/3) of its observing time will be allocated to Key Programs in the form of large spatial and spectral surveys.

PACS and SPIRE were design for large-scale unbiased surveys of the high-z universe to study the history of energy production, structure formation, cluster evolution, lensing, cosmic IR background fluctuations, and the AGN starburst connection. Likewise, HIFI was designed to uniquely probe water in the universe through high resolution studies of the pure rotational transitions of H_2O and to provide an inventory of the molecular universe through unbiased spectral scans of the "full" sub-millimeter wavelength band. The guaranteed time and open time Key Programs will be selected in 2007, about a year before launch. A call for normal open time programs for the remainder of the available time (nominally ~1 yr of observing time) is scheduled for 6 months after launch.

SOFIA and Herschel

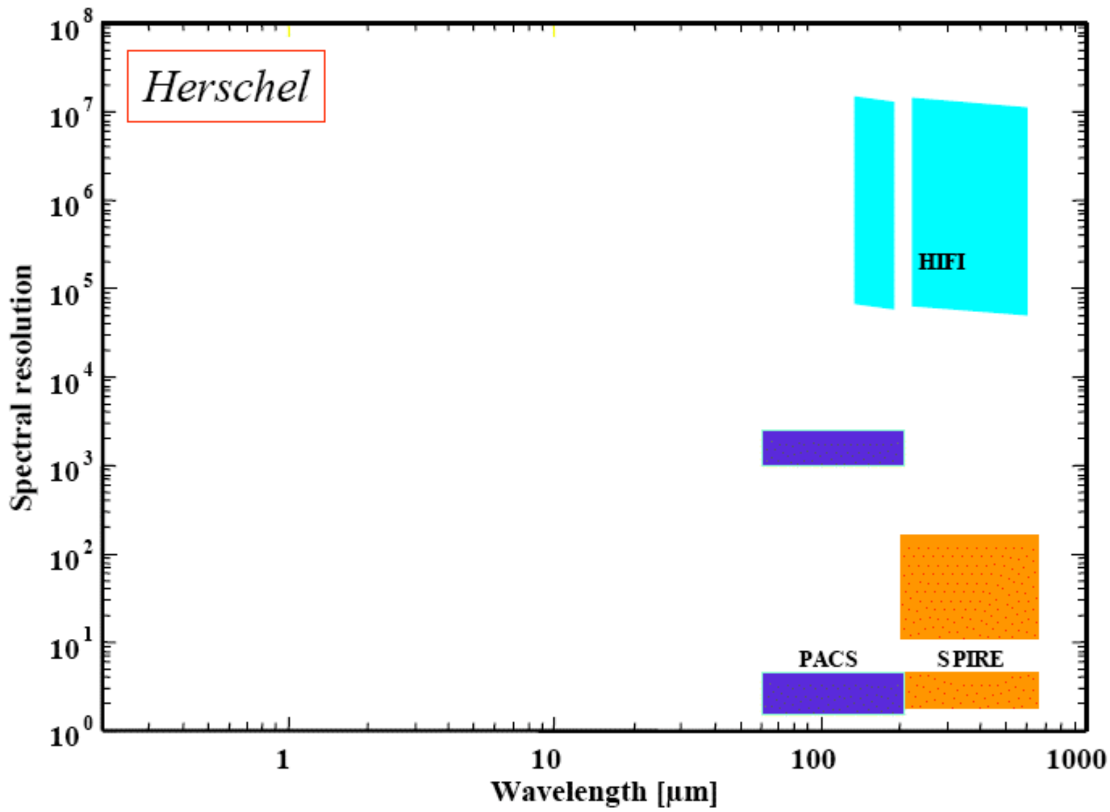

Figure 2: Wavelength coverage and spectral resolution of the instruments on Herschel.

As a comparison between Figures 1 and 2 illustrates, the SOFIA and Herschel instruments in the far-IR and sub-millimeter show some overlap in terms of wavelength coverage and spectral resolution. Specifically, we should directly compare imaging with HAWC on SOFIA with PACS on Herschel, high resolution spectroscopy with the heterodyne instruments CASIMIR and GREAT on SOFIA with HIFI on Herschel, and the submillimeter instruments SAFIRE on SOFIA and SPIRE on Herschel. Since some of SOFIA's instrument complement has no Herschel counterpart, we will also address the complementarity of SOFIA's mid-IR instruments to Herschel far-IR and sub-millimeter studies, as well as SOFIA's future instrumentation and science programs after Herschel runs out of superfluid helium.

A) HAWC versus PACS

The HAWC camera on SOFIA can be compared directly to the PACS bolometer camera on Herschel. Whereas HAWC employs a single 12 x 32 bolometer array, the PACS camera employes two arrays – a blue 32 x 64 channel and a red 16 x 32 channel. The PACS camera is slightly more than an order of magnitude more sensitive than HAWC, in part, because of the larger telescope aperture and broader filter bandwidths but mostly because of the lower thermal background of space. The PACS camera is optimized for sensitive imaging in three broad bands (R = 2.3) centered on 71, 105, and 165 microns. During normal imaging operations, the PACS blue (71 or 105 microns) and red (165 microns) channels operate simultaneously. Whereas the PACS camera provide nyquist sampling with two bands (the 105 and 165 micron bands), the HAWC camera on SOFIA provides nyquist sampling in each of four bands centered on 53, 89, 115, and 216 microns. By design, the HAWC optics match SOFIA's diffraction limited performance over somewhat narrower filter passbands (R = 5.5). Whereas the PACS field of view is 105" x 210" for both the blue and red channels, the HAWC fields of view varies from 27" x 72" at 53 microns to 96" x 256" at 216 microns. At the shortest wavelengths, HAWC could accommodate a much larger detector (up to 128 x 128) for unvignetted imaging without any modification to the existing optics should such a device become available.

If both instruments work as expected, PACS will be much more efficient for the mapping and imaging of faint sources. For bright, complex sources, the narrower filters of HAWC and the instrument's broad wavelength coverage (a factor of 4 vs. 2.3) are an advantage in the determination of spectral energy distributions. For the broader PACS filters, Herschel's Airy function is 50% larger at the long-wavelength half-power point than at the short-wavelength half-power point. HAWC's narrower filters (R = 5.5 vs. R = 2.3) minimize the convolution of spatial and spectral information.

Given the limited lifetime of the Herschel mission, HAWC and PACS should be used in complementary ways. Existing surveys like the Sloan Digital Sky Survey have convincingly demonstrated the importance of maximizing the size of data sets so that the maximum value can be extracted from them. Using HAWC for detailed observations of bright, complex sources can free PACS to devote more time to critical surveys. Conversely, the PACS data set will inevitably raise questions that can best be addressed by taking advantage of the more focused capabilities and flexibility of HAWC.

Thus, while both bolometer cameras are designed for imaging and SED evaluation, PACS key science is the detection and resolution of distant galaxies in the far-IR. In contrast, the narrower filters of HAWC seek to reduce the convolution of image quality with spectral intensity. These design differences will drive the observational strategy: Herschel/ PACS observations are best spent in mapping extended sky emissions at level below SOFIA/HAWC's current sensitivity range whereas SOFIA/HAWC should focus on bright compact regions identified by Herschel. In principle, the bright point sources could be done with Herschel but – in view of the limited operational lifetime of Herschel – this would then be done at the expense of fainter regions not doable from a suborbital platform like SOFIA.

B) CASIMIR and GREAT versus HIFI

The heterodyne instruments, CASIMIR and GREAT, on SOFIA can be directly compared to the HIFI instrument on Herschel. All of these instruments are designed for velocity resolved spectroscopy at the (sub) km/s level of interstellar and circumstellar gas. At low frequencies (□<1THz; eg., □>300um), both CASMIR and HIFI will be quantum noise limited. HIFI is then expected to have a slight edge (factor 2) in sensitivity because of Herschel’s larger telescope aperture. However, this advantage is lost when mapping of extended emission zones is important and ultimate spatial resolution is not the driving force; eg., diffuse interstellar gas emission. Because of its stable space-based platform and the contiguous spectral coverage unaffected by telluric absorption, HIFI will be particularly suited for full spectral scans that probe the full molecular inventory of, for example, regions of star formation, circumstellar gas, and the interstellar medium. In addition, HIFI will be the only instrument capable of probing a wide range of H_2O lines in such environments at high spectral resolution. HIFI’s planned Key Programs and likely the open time programs as well, focus on these types of observations, which cannot be done by any other observatory. Except for the water lines, CASIMIR on SOFIA will be very competitive for studies of known spectral lines. These include, in particular, the pure rotational transitions of small hydrides which are the starting point of all gas phase chemistry and hence will be essential to understand the chemical evolution of the ISM as well as the low lying ro-vibrational transitions of carbon chains and polycyclic aromatic hydrocarbon species which are the key to understanding the molecular complexity of the universe. Given the limited operational lifetime of Herschel, optimum strategy might then be that HIFI surveys the molecular universe and that CASIMIR follows up with detailed studies of objects in the most suitable lines.

At high frequencies (□>1 THz), heterodyne instruments presently do not reach quantum noise performance but heterodyne instruments on SOFIA are well poised to reap the benefits of rapidly improving detector technology. Both GREAT on SOFIA and HIFI on Herschel cover the 1.4-1.9 THz range and, for compact sources, HIFI is expected to be a factor ~2 more sensitive than GREAT in this range due to the difference in telescope aperture. This frequency range contains the [CII] fine-structure transition, which COBE has shown to dominate the cooling of the diffuse interstellar gas and hence the phases of the interstellar medium. The high spatial resolution of HIFI or GREAT will restrict spatial studies of the [CII] line to compact bright sources and, for example, HIFI has currently limited plans for [CII] mapping. Besides the 150-200 □m window, GREAT also has two higher frequency channels at 100 and 63 μm that are not covered by HIFI on Herschel. The 100 μm channel is designed to search for the ground state transition of HD and hence will probe the cosmologically important D abundance and its astration by nuclear burning in stars. The 63μm channel will provide unique spectra of the [OI] 63 μm line at the km/s level. This line dominates the cooling of warm and dense gas such as associated with PhotoDissociation Regions, shocks in molecular clouds, and envelopes around protostars as well as stellar ejecta. While PACS on Herschel covers the [OI] transition, the high spectral resolution of GREAT will be imperative to assess optical depth effects, which are bound to be important in all astronomical objects probed by this line, as well as to separate different emission regions within the same beam – such as a collapsing protostellar envelope, rotating protoplanetary disk, and protostellar outflow – through their dynamical signatures.

C) SAFIRE versus SPIRE

Both SPIRE on Herschel and SAFIRE on SOFIA operate in the sub-millimeter window. These two instruments are designed to pursue fundamentally different scientific questions. With its large-scale arrays (4x4' field of view and 17-35" pixels), SPIRE can simultaneously map the sky in three broad bands at 250, 250 and 500 μm. This instrument is specifically designed to carry out large area, deep photometric imaging surveys at far-infrared and submillimetre wavelengths. In addition, SPIRE has a low resolution fourier transform spectrometer. SPIRE's science focuses therefore on the characteristics of galaxies and structure formation at high redshift, as well as the spectral energy distribution during the first stages of deeply embedded star formation. SAFIRE, on the other hand, is a versatile Fabry-Perot imager and spectrograph that covers the 145-650 μm range with spectral resolving powers ranging from 5 to 10^4. However, at a spectral resolution of R = 1000, SAFIRE is expected to be a factor of 2 more sensitive then the SPIRE FTS at 250 microns and a factor of 10 at 650 microns. SAFIRE's science goals focus on imaging of interstellar and circumstellar environments in atomic, ionized, and molecular transitions along with the dust emission, particularly those associated with star formation, starburst galaxies, and galactic nuclei. SAFIRE imaging and spectroscopic capability will provide a strong diagnostic tool for studying sources discovered by SPIRE. Of particular relevance here, while SPIRE is designed to provide a census of the galaxy population in the sub-millimeter sky, SAFIRE is the only instrument capable of measuring the dominant [CII] 158 μm lines for galaxies in the important 0-1 redshift range and hence determine the characteristics of the neutral gas and the structure of the interstellar medium during this important era in the star formation history of the universe. SAFIRE can also observe the [NII] line at 205 microns at low z and at 122 microns (characteristic for the Warm Ionized Medium of the ISM of galaxies) for moderate z and beyond. As these interstellar gas diagnostics need to be studied over time in a systematic fashion from z = 0.1 to z = 1 to z > 5, SOFIA will be necessary to cover low z whereas ALMA will be required for higher z observations of [CII] redshifted to the sub-millimeter. Of course, for luminous galaxies at such high redshifts, the [OI] line at 63 μm may well take over the cooling from the [CII] line and become the most important line to observe and SAFIRE is (again) the only instrument that can probe this line in the redshift range exceeding 1.3.

D) Mid-IR complementarity

Herschel will be launched well after Spitzer's last call for proposals, now scheduled for early 2007, and SOFIA will then be the only platform providing routine access to the mid-IR range and able to complement Herschel's far-IR and sub-millimeter studies in the mid-infrared. Experience with ISO and Spitzer has taught us that many objects have very broad spectral energy distributions and show spectral detail – ranging from broad dust features, to moderate PAH bands to narrow atomic and molecular emission lines – over the full range of infrared wavelengths. Complementary mid-IR studies are then imperative to develop full insight in the total spectral energy distribution of sources or source components, their dust and gas constituents, and the spatial interrelationship of sources detected by Herschel in the far infrared. With its versatile instrument complement, SOFIA is well suited for such complementary studies.

Such studies will include imaging with FORCAST of interstellar and circumstellar regions in the Polycyclic Aromatic Hydrocarbon emission bands that dominate the mid-IR spectral energy distribution of almost all objects, including HII regions, reflection nebulae, planetary nebulae, galactic nuclei, the general diffuse ISM, starburst galaxies, and UltraLuminous InfraRed Galaxies. Such observations would complement studies of the composition and chemistry of the molecular universe in the far-IR and sub-millimeter. Moreover, these molecules are generally thought to play an important role in the energy balance of neutral and molecular interstellar gas through the photoelectric effect as well as the ionization balance of diffuse and dense gas. FORCAST on SOFIA will be the only instrument able to probe these aspects of the molecular universe in support of Herschel.

Likewise, EXES on SOFIA will provide a unique high-resolution capability over the 5-28 μm range. This wavelength range covers the fundamental ro-vibrational transitions of most molecular species as well as many important atomic and ionic fine-structure lines. Specifically, in the context of Herschel complementarity, EXES will be able to probe the ro-vibrational transitions of H_2O around 6 μm. These lines are prominent in regions of massive star formation. Likely, these transitions play an important role in setting the excitation of the pure rotational transitions probed by HIFI on Herschel in these objects and hence the EXES observations will be key to fully understand the physical conditions in these regions. In addition, EXES can probe the presence of species without permanent dipoles that lack a pure rotational transition spectrum at the low frequencies probed by HIFI and CASIMIR. These include the simplest, but from a chemical point of view fundamental, hydrocarbons, C_2H_2 and CH_4.

The mid-IR spectral range also contains the fine-structure transitions of atoms and ions, including SiII, SI, SIII, SIV, NeII, NeIII, ArII, ArIII, and OIII. These highly diagnostic lines can be used to probe the physical conditions in ionized and neutral atomic gas, including density, temperature, dynamics, and energetics.

E) Future instruments

In many ways, far-IR and sub-millimeter instrumentation is still in its infancy and rapid strides in detector technology and instrument development can be expected over the next two decades. SOFIA will be driving efforts in these areas through a vigorous technology and instrument development program, offering rapid application of new instrumentation to astronomical problems. Specifically, it will be important to optimize instruments employing heterodyne techniques at high frequencies (ν>1THz). Such instruments will be the most sensitive high-resolution spectrographs available – another order of magnitude can be gained in sensitivity – and SOFIA will be the only observational platform available that can give routine access to the THz window.

Likewise, SOFIA will stimulate the development of large-scale arrays employing heterodyne receivers. Such an imaging spectrometer will be able to efficiently map extended emission regions in specific atomic or molecular lines at km/s resolution and will be the only way, for example, to study the dominant [CII] 158 μm fine-structure line in the diffuse interstellar medium.

Another area where SOFIA's instrument program can open up unique new capabilities is by driving the development of far-IR polarimetry instruments. These will allow imaging of the magnetic field structure in for example regions of star formation as well as in the nucleus of our Galaxy. Many physical phenomena in those regions are tied to the magnetic field and its interaction with matter and currently there is no instrument that can probe this.

As a sub-orbital program, SOFIA's science instrument suite can be up graded to accommodate new technologies as they become available throughout the observatory's operational lifetime. The HAWC instrument, for instance, can accommodate additional combinations of filters, grisms, focal scales, and pupil and coronographic masks. Both CASIMIR and GREAT can accommodate improved mixers and local oscillators. And most of SOFIA's instruments can accommodate novel and innovative science-enabling detector technologies indicative of a most robust and dynamic sub-orbital programs.

F) SOFIA: beyond Herschel

After Herschel runs out of liquid Helium – nominally 3 years after launch – SOFIA will be the only platform providing routine access to the far-infrared and sub-millimeter window. We can envision many years of follow-up science on the far-infrared and sub-millimeter universe revealed by Herschel's deep spatial surveys which will be required to reap the full benefits of the opening up of this new spectral window on the universe.

In addition, the James Webb Space Telescope is currently scheduled for launch in 2013 and will operate in the mid-IR range using large scale, sensitive imaging arrays and moderate resolution spectrometers. Over the 5 to 10 years of JWST's operational lifetime, SOFIA will be the only observatory capable of 30-650 μm follow up of discoveries made by JWST as well as of providing ancillary mid-infrared data such as, for example, high spectral resolution observations to probe the dynamics of new objects. In this case as well, this follow-up will benefit greatly from the availability of a wide range of instruments on SOFIA.

Appendix I

SOFIA will have three classes of instruments:

i) Facility-class Science Instruments are general purpose, reliable and robust instruments that provide state-of-the-art science performance at commissioning, through the use of modern, but mature technologies. It is expected that this instrument will be routinely operated and maintained at the SOFIA Science and Mission Operation Center in support of general investigators.

ii) Principal Investigator-class Science Instruments are general purpose instruments developed and maintained at the state-of-the-art throughout its useful operating life. It is expected that this instrument will be operated by the Principal Investigator team, both for its own research as well as that for general investigators. Normally, the instrument will reside at the principal investigator's institution where all maintenance and upgrades will be accomplished.

iii) Special Purpose Principal Investigator-class Science Instruments are specifically designed for a particular observation or set of observations not possible or practical with Facility-class or Principal Investigator-class Science Instruments. Normally, the instrument will reside at the principal investigator's institution where all maintenance and upgrades will be accomplished.

The characteristics of the First-Generation instruments are summarized in Table 1.

SOFIA's suite of funded first generation instruments

Instrument	PI	Institute	Type of Instrument	Instrument Class
HIPO	T. Dunham	Lowell Observatory	High-speed Imaging Photometer for Occultations 0.3 – 1.1 microns	Special Purpose Instrument (Test Instrument)
FLITECAM	I. McLean	UCLA	Near-infrared test camera 1 – 5 microns	Facility Instrument (Test Instrument)
EXES	J. Lacy	Univ.of Texas	Echelon Spectrometer 5 – 28 microns R=10^5, 10^4, 3000	PI Instrument
FORCAST	T. Herter	Cornell Univ.	Mid-infrared camera 5 – 40 microns	Facility Instrument
GREAT	R. Guesten	MPIfR KOSMA DLR-WS	Heterodyne Spectrometer 60 – 200 microns	PI Instrument
CASIMIR	J. Zmuidzinas	Caltech	Heterodyne Spectrometer 250 – 600 microns	PI Instrument
FIFI-ls	A. Poglitsch	MPE, Garching	Imaging Grating Spectrometer 42 – 210 microns	PI Instrument
HAWC	D. A. Harper	Univ.of Chicago	Far-infrared bolometer camera 50 – 240 microns	Facility Instrument
SAFIRE	H. Moseley	NASA-GSFC	Imaging Fabry-Perot Bolometer array spectrometer 145 – 655 microns R = 1000 to 2000	PI Instrument

Additional information on SOFIA and the observatory's instrument suite is available from http://www.sofia.usra.edu or http://sofia.arc.nasa.gov .