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Early Science Opportunities with SOFIA

1.0 Introduction

NASA's new Stratospheric Observatory for Infrared (IR) Astronomy (SOFIA) is now undergoing its final phases of flight testing and will begin science operations early in 2009. A process to involve the U.S. scientific community in developing SOFIA's early science program began with a workshop at the Austin January 2008 AAS meeting. The principal objective of the workshop was to initiate a community-wide effort to identify cutting-edge scientific investigations that will require and capitalize on SOFIA's unique capabilities. Attendees heard the latest information about the SOFIA mission and the observatory's instruments and scientific capabilities, and then divided into five Working Groups (WGs) to begin drafting a report on five main science and programmatic themes that SOFIA might fruitfully pursue during the early phases of its mission. The five themes addressed by the WGs were:

- Stars and Star Formation
- The Chemical Evolution of the Universe
- Extra-Solar and Solar System Planetary Science
- Extragalactic Science
- Community Knowledge Base (CKB) Observing Programs

Work initiated by the WGs at the workshop was continued and expanded during the period between January 15, 2008 and April 1, 2008, when final results were presented to the workshop chairs for integration into a final report. This White Paper summarizes the deliberations of the WGs effort and represents the cumulative product of the workshop.

2.0 Stars and Star Formation (Chair: John Bally)

The investigation of stellar and planetary birth, life, and death is a central theme in astrophysical research. Star formation determines the cosmic fate of baryonic matter.

2.1 Probing the "Cosmic Ecology" of Stars and Planetary Systems

The star formation rate (SFR) in a galaxy determines how rapidly the interstellar medium (ISM) is converted into stars, planets, and smaller solid bodies. The initial mass function (IMF) determines how long baryons are locked-up in compact objects, precluding them from participation in the "cosmic ecology". Massive stars convert primordial H and He into all elements of the periodic table and recycle a portion of this matter back into the ISM on a timescales of 40 megayears. Their cores collapse into neutron stars or black holes. Stars with masses ranging from 0.8 to 8 Solar masses synthesize the lighter elements, return a portion to the ISM on times-scales ranging from 40 Myr to the Hubble time, and sequester the rest in white dwarf remnants. Stars below 0.8 Solar masses lock-up baryons for longer than the current age of the Universe; no such star has ever died of natural causes in this Universe. Since the transformation of baryons from the ISM into stars and planets and back into the ISM occurs in dust enshrouded environments at relatively low temperatures, most emitted radiation emerges at IR wavelengths.

- SOFIA provides unique access to the 1 :m - 1 mm spectrum where most radiation produced by the ISM, forming and dying stars, and warm circumstellar matter emerges. In the two decades, SOFIA is the only facility that will provide access to the mid-IR between 25 and 60 :m where warm ~100 K dust and gas radiates. SOFIA will provide capabilities complementary to those of other IR facilities (Gemini, Keck, VLT, LBT), soon-to be-built extremely large telescopes (ELTs), the new generation of synoptic-survey telescopes (LSST, PanSTARS), new mm/sub-mm facilities such as CARMA and ALMA, and space-based platforms (JWST, Herschel). SOFIA will provide access to the thermal IR regime where ground-based telescopes are blind. JWST provides access only to wavelengths below 29 :m and only with low spectral resolution ($R < 3,000$). Herschel provides broad-band filters down to 60 :m and single pixel heterodyne capability at selected frequencies. SOFIA will provide high spectral resolution $R > 10^4$ and angular resolution of $\theta_{min} \sim \lambda/10$ in arcseconds where λ is the wavelength in :m.

- SOFIA will provide high spectral resolution and nearly complete access to the thermal IR with spectral resolution much greater than JWST, Spitzer, and Herschel (below 60 :m). SOFIA will provide better angular resolution than Spitzer, IRAS, and ISO, and access to the bright sources where Spitzer saturates.

- SOFIA provides unique access to time-critical and synoptic observations. It can achieve super-resolution by using cold outer-Solar system bodies (KBOs, asteroids, etc) as occulters and by making multiple passes through the transit shadow.

- SOFIA will enable use of unique filters, detectors, and instruments that will be unavailable from space or the ground. SOFIA will serve as the first-light test-bed for second-generation IR instrumentation. Within the next decade, broad-band incoherent focal plane arrays which can simultaneously detect multiple colors (MKIDs) will become available. Multi-feed heterodyne cameras will enable SOFIA to take advantage of spatial multiplexing.

- During its first five years of operations, SOFIA will bridge the wavelength gap between the visual/near-IR and sub-millimeter regimes where ground-based facilities operate, and will provide the high spectral resolution and spatial-multiplexing not available on near-term space-based facilities.

The potential of SOFIA to enable new insights into the processes of star and planet formation can be grouped into three themes: 1) How do stars and planets form?, 2) How does material transition from the ISM into mature planetary systems?, and 3) How is material returned to the ISM? Near-term SOFIA research may be driven by the results of surveys. Several mm and submm continuum surveys of the Galactic plane and nearby star forming regions are underway or will soon start at facilities such as the CSO, JCMT, and APEX. For example, the 1.1 millimeter Bolocam Galactic Plane Survey (BGPS) has mapped 150 square degrees of sky at 30" resolution, finding about 10,000 cloud cores. By 2009, the Herschel Space Observatory and SCUBA2 surveys of the Galactic plane will be providing maps from 60 to 850 :m. Complementary near-IR (< 3 :m) and to mid-IR (3 to 24 :m) surveys are also being obtained (e.g. VISTA, GLIMPSE, MIPSGAL, etc.) from the ground and with Spitzer. By 2010 to 2012, these surveys will provide new lists containing thousands of regions in our Galaxy where stars and clusters are about to, or are actively forming, or where stars and their planetary systems are dying. SOFIA will be the principle tool for investigating this "Galactic Ecology".

Undoubtedly, unexpected discoveries will emerge from the opening of new regions of parameter space. Emerging facilities (JWST, ELTs, LSST) and new technologies during the next decade may trigger new types of observations with SOFIA. Key areas to watch for new developments and breakthroughs include detection of dark matter particles, new constrains on the nature of dark energy, properties of ultra-high energy cosmic rays, developments in astrobiology, the identification and characterization of extra-Solar planets, the first stars and galaxies to emerge form the Universe, small-scale studies of the CMBR and its polarization, new particles detected at high energies by LHC, and cosmic-ray studies.

These disciplines and emerging wide-field synoptic programs will drive future SOFIA research towards time-domain work. Examples include monitoring SN, time-evolution of gravitational lensing events, weather patterns on planets, monitoring of both short-timescale and long-time-scale evolution of systems such as GRBs, AGN, stellar mass-blackholes, micro-quasars, evolution of shocks in various contexts, proper motions, parallaxes, and other types of synoptic change.

Moore's Law, developments in solid-state physics, and nano-technology are likely to lead to many orders-of-magnitude improvement in data processing, storage, and transmission and these technologies are likely to lead to new types of detectors, receivers, and focalplane arrays. These factors may create major upgrade opportunities to SOFIA on a 10 year horizon that will make it an increasingly important facility for astrophysical research.

Below, we discuss likely examples of SOFIA-based studies in each of the above three theme areas as an illustration of the utility of SOFIA to enable new understanding in these areas.

2.2 The Formation of Stars and Planets

High-R spectroscopy and spectro-imaging in the SOFIA spectral domain will illuminate many key questions in star and planet formation. Some specific observations that can be made with SOFIA include:

The structure and spectral energy distributions (SEDs) of forming stars and clusters: Key targets include the nearest star forming complexes and their cores. These include L1551, Taurus, Ophiucus, and Orion OMC-2, and the nearest massive star forming regions such as Orion OMC1 and Cep-A. More massive cluster forming regions such as DR21, G34.15+0.26, Sgr B2, and the Galactic Center will probe the highest mass cluster and massive star-forming regions in our Galaxy. FORCAST and HAWC will provide the highest resolution imaging and photometry capability in the 5 to 250 µm regime where most of the luminosity emerges. Key questions to answer with SOFIA mid-IR imaging are: How do clouds fragment into clusters and stars? What are the structure functions ("correlations") of warm dust and young stars?

The physical and chemical properties of star forming regions: SOFIA will make essential mid-IR observations of massive star and cluster birth, including the evolution of cores into "hot-cores" hyper-, ultra-, and compact HII regions, into mature star complexes and associations at the peak of their emitted spectra. Continuous coverage of the mid-IR from 5 to about 100 :m provides high spatial and spectral resolution where most YSO luminosity emerges. Representative targets can be observed with SOFIA spectrometers to determine their emission spectra, kinematics, and spatial structure. The spectral lines of hydrogen, nobel gases, various ions, and molecules in both gas and solid-state phases will be diagnostics of compositions, spatial and velocity structure, and the physical and chemical conditions in star forming regions.

Energy-balance in the ISM: Owing to its broad spectral coverage, SOFIA can uniquely address the cooling rates of various phases of the ISM by means of high-spectral resolution. The broad spectral-coverage of SOFIA is especially important for the investigation interface regions and post-shock cooling layers where temperatures can range from 10s to millions of Kelvin within sub-arc-second to 10s of arc-second scales. The heating and cooling of photo dissociation regions (PDRs), Herbig-Haro objects, the diffuse ISM, molecular clouds, and hot cores is dominated by IR emission. Even the warm and hot phases of the ISM have abundant IR tracers. Key tracers include C+, OI, OIII, NII, SIII, SiII, SiIV, ions of noble gasses (Ne V, Ne III, Ne II, Ar V, Ar III, Ar II) and a variety of gas-phase and solid-state molecular transitions of common species (H2, CO, CO2, H2O, OH, etc.).

Magnetic fields: Imaging polarimetry with SOFIA will trace grain alignment and the magnetic field geometry. Spectro-polarimetry of various spectral lines such as the 24 :m Fe complex and Zeeman sensitive molecules such as OH may provide a powerful tool for the determination of strong magnetic fields expected in massive star forming regions, disks, and in ultra-dense environments such as the Galactic center.

Massive star and cluster birth: The densest phases of massive star formation during which most of their mass is assembled requires the mid-IR observations provided by SOFIA. Do massive stars and clusters form by competitive accretion or from scale-up disk accretion. Do the most massive star clusters form in a "cooperative" where the Eddington luminosity re-directs accretion onto less-massive, less-luminous siblings? EXES, FIFI-LS, GREAT, CAIMIR, and SAFIRE will provide unprecedented high-R spectral coverage of the IR. Tracers such as 12 :m [NeII] provide both spatial and spectral resolution. H2, CO, and fine-structure lines will probe the structure and velocity fields of jets and the primary drivers of molecular outflows beyond the Solar vicinity where extinction prevents near-IR and visual-wavelength studies. Mid-IR tracers will probe the low-shock speeds where outflows degrade into turbulent and thermal energy.

The "Galactic Ecology" - Feedback and Self-Regulation of by Massive Star Formation: SOFIA observations are needed to probe how massive stars regulate the physical and chemical state of the ISM. Fine-structure lines, H2, other species are needed to follow the degradation energy injected in the form of photons, particle winds, and explosions into radiation and turbulent motions in the ISM. The spectro-morphology of star forming regions will be used to study how energy injection drives the transformations of the ISM phases into each other. How do OB associations, massive stars and clusters, and Galactic processes drive the ecology of the ISM?

Outflows and Feedback from Low-Mass Stars: In the absence of high-mass stars, protostellar winds may be the primary agent for the self-regulation of star formation. SOFIA spectroscopy of jets and molecular outflows using a variety of tracers such as fine-structure lines, molecules, H2, and recombination lines are needed to evaluate the mass, momentum, and energy injected by winds and jets into the ISM.

The Galactic Center: The center of the Milky Way provides access to the environment of the nearest super-massive ($M \sim 3 \times 10^6\ M_\odot$) black hole (BH). The approximately $A_V = 30$ mag extinction precludes observations from the near-IR through soft X-rays. IR observations with SOFIA will shed unique light on the accretion processes, fueling, and growth of the BH, the formation of stars in the circum-nuclear environment where the Keplerian orbital motion about the BH dominates, and of the properties of the nuclear interstellar medium (NISM) and star systems. The Galactic NISM consists of ultra-dense molecular clouds and a variety of exotic thermal and non-thermal features such as the radio-filaments, the circum-nuclear spiral, the "Arches" filaments, energetic stellar wind bubbles from the nuclear cluster of massive stars, and ablating red-giant atmospheres. The stellar population in the inner parsec reaches its highest space density anywhere in the Galaxy ($>10^7$ stars pc^{-3}), contains exotic high-velocity stars in orbit around the BH, and a remarkable collection of massive Wolf-Rayet and massive stars that must have formed recently in extreme conditions. Massive star birth in a circum-BH disk may be analogous to planet formation around normal stars. Many massive star remnants (neutron stars and stellar-BHs) are expected to be interacting with the NISM. For example, it has been proposed that the "Great Annihilator" – one source of 511 keV positronium line emission - may be a stellar mass BH accreting from the NISM. IR spectroscopy will provide unique tests of the interactions of relativistic particles with dense molecular gas. SOFIA will provide unique spectral probes of the gas and dust in the central parsecs, spectroscopy and spectral-typing of massive stars and clusters in the GC, and imaging and spectroscopy of the non-thermal filaments. Are these filaments similar to Herbig-Haro objects near the Sun, but much larger and more luminous? Do they contains strong magnetic fields? SOFIA will provide unique probes of the IR environment of stellar-mass black-holes, neutron stars, other collapsed objects. It will enable searches for gravitational lensing events of background stars by the central super-massive black hole. Finally, detailed investigations of the massive star forming regions that abound in the Central Molecular Zone will shed light on nuclear starbursts in other galaxies, and the behavior of the NISM in response to the forcing by the central stellar bar.

2.3 The Transition of Material from the ISM into Mature Planetary Systems

The closest young stars and forming planetary systems: Spitzer, HST, Chandra, and ground-based studies have identified thousands of young stellar objects (YSOs) within 500 pc of the Sun. The formation and early evolution of planetary systems requires IR observations in the SOFIA spectral range (1 to 300 :m) because planetary system formation occurs in disks where the temperature ranges from about 10 to 1000 Kelvin. High spectral resolution studies of disks around the youngest YSO will be used to determine disk sizes, structure, and composition. SOFIA spectroscopy of the closest YSO such as those in Taurus , Ophiuchus, Lupus, and Chamaeleon will provide complete spectral energy distributions (SEDs) and detailed constraints on excitation, ionization, and composition.

"Proplyds" and the first steps to planet formation: Nearby regions such as the Sco-Cen OB association, the Perseus Clouds, and Orion contain hundreds of low-mass stars thought to be forming planetary systems. SOFIA will be especially well suited to the study of photo-ablating proto-planetary disks (e.g. the "proplyds" such as those observed with HST in the Orion Nebula). Although these irradiated disks will be unresolved, IR spectroscopy with SOFIA will enable global properties such as dust mass (spectral distribution of dust continuum), mass-loss-rate (flux and velocity of various lines), grain size and composition (shape and strength of the 10 and 20 mm silicate feature, ices, and PAH spectra), to be determined. Emission spectroscopy will be used to infer the abundances of gas and solid state features, determine the nature of ices, and measure grain size distributions. Polarization and Zeeman studies will be used to constrain the geometry and strengths of magnetic fields.

Maturing Planetary Systems: As samples of YSOs and young stars having ages ranging from less than on million to nearly a billion years become available (from Spitzer, Hershel, and ground-based studies), SOFIA imaging and spectroscopy will be used to measure the lifetimes of primordial circumstellar disks as functions of stellar mass, binarity, and birth environment. SOFIA will trace the transition to debris disks, and estimate their longevity and evolutionary behavior. Do debris disks come and go as grains are lost and re-supplied by proto-planetary collisions? Are debris disks produced primarily by collisions, by the evaporation of smaller icy bodies, or the collisional erosion of planetismals? Imaging and spectro-imaging studies of more evolved YSO disks will detect the secondary dust produced by collisions of planetary embryos, and more mature protoplanets as functions of stellar age, mass, and birth environment. Spectral studies of solid state features (silicate features, ices, and various stretch and bending modes of molecules locked into grains) will enable mineralogical studies of debris disks such as AU Mic (located a mere 12 pc from the Sun), Vega, ß-Pictoris. SOFIA will search for and probe the properties of disks around multiple stars identified by other means to investigate the impact of multiplicity on disk evolution.

Balog tails: A remarkable result from Spitzer is the detection of 24 :m (and in some cases 8 :m, and in one case near the central star of Tr 14, at 3 :m) light from 0.1 pc long dust tails driven away from low-mass stars that happen to be close to O stars (e.g. Balog 2006). These tails are gas-free and appear to be blown out from forming planetary systems by the intense radiation pressure of the O star. The origin of the dust is unclear. It may signal the prompt decay of a debris disk in a harsh radiation environment ("debris disk blow-out"), the rapid evaporation of icy parent bodies, or dust production caused by the collision of large planetary embryos. SOFIA is the only instrument capable of spectroscopy (e.g. the silicate features), to constrain models.

Occultation studies ("natural coronagraphy"): SOFIA's mobility will enable unique super-resolution studies of a variety of targets using asteroids and KBOs as occulters. This capability may be especially useful for the NIR investigation of debris disks systems because SOFIA mobility may enable the central star to be occulted. There is a chance that SOFIA may be able to directly image and characterize giant planets around the nearest stars by using asteroids or KBOs to suppress the light of the host star.

2.4 The Return of Material to the ISM

Winds and Outflows from Mature Stars: SOFIA spectroscopy of obscured stars and wind bubbles will extend our understanding of winds throughout the Galaxy, enabling the study of their dependencies on metallicity and environment. Ordinary stellar winds provide the first means by which stars recycle the products of stellar nucleosynthesis into the ISM. Massive star winds can be detected in both in the stellar spectra and by the forward shocks driven into the ISM. IR spectroscopy of emission line Be stars will probe the cool outer disk material and shed light on their unique mass loss mechanisms. Is the Be phenomenon connected to stellar magnetic activity and fast rotation? Mass-loss rates and the dredging of synthesized material increase dramatically as stars evolve off the main sequence. IR spectroscopy of K and M giants, supergiants, OH/IR stars, WR stars, LBVs, and other types of post-main sequence (PMS) objects will probe the formation and composition of grains by means of the PAH features, C-C, C-H and other stretch and bending modes, 10 and 30 :m silicate, and other IR band bands. Gas phase enrichment and metallicity patterns can be probed by spectroscopy of the rich variety of noble gas and fine-structure transitions of atoms and their ions, molecular rovibrational spectra. The IR emission from objects transitioning from the main-sequence to the postmain sequence phase will provide definitive measurements of mass-loss rates as functions of stellar mass and age. Does most mass-loss occur in brief and violent eruptions during certain stages of stellar evolution? IR studies of the shells of rare luminous blue variables (LBVs), and eruptive stars such as AG-Car and P-Cyg will provide constraints.

Binaries and mass-transfer systems: The evolution of stars in close binaries can lead to mass loss and a variety of exotic stellar behaviors such as symbiotic stars, intense variability, and the nova phenomenon. Stars in close binaries can exchange mass and alter the normal course of stellar evolution. Roche-lobe overflow can result in the formation of expanding rings and disks. Giant circumstellar rings have been discovered around a variety of stars when externally illuminated by nearby massive stars. Examples Include WeBo 1, an 80,000 AU diameter ring surrounding a barium star (Bond 2003), the eqauatorial ring around the supergiant Sher-25 in NGC 3603, and the triple ring system in SN 1987A. Multiple ring-systems have recently been discovered around several Be and LBVs (Smith et al. 2007). Since most shed circumstellar rings are cool, SOFIA IR observations are required to detect and characterize them.

Stellar Death: Stars of all-masses enshroud themselves in dust cocoons that reprocess most of their visual and NIR light into thermal IR radiation in the SOFIA-accessible wavelength regime. High resolution spectroscopy of dusty stellar envelopes such as proto-planetary nebulae (PPN), and objects such as IRC10216, IRC10420, ?-Carina, Betelgeuse will be used to measure wind composition, geometry, mass-loss rate and velocity history, gas-to-dust ratio, and the interaction of these flows with the surrounding ISM.

Spectro-imaging of PPN and planetary nebulae will provide the most reliable method for determining the metallicity of recycled circumstellar matter. Noble gasses and their multiple ionization stages are accessible in the IR (e.g. Ne and Ar). Their equivalent widths in planetary nebulae are robust indicators of excitation conditions and metallicity. Solid state and ice features will probe gain formation, composition, and mineralogy.

Stellar Remnants: The stellar graveyard consists of white dwarfs (WDs) , neutron stars (NSs), and black holes (BHs). IR emission from the circumstellar environments of remnants indicates that as the cores of dying stars collapse, not all envelope material is recycled or incorporated into the collapsed object. Some high-angular momentum core material from the dying star collapsed into a "fall-back" disk. Disks surrounding remnants can undergo processes analogous to planet formation, producing solid bodies observed as pulsar planets. Collisions between such bodies can produce dust and IRexcess emission. The surface pollution of WDs by the accretion of gains and gas from fall-back disks may be responsible for exotic surface compositions. SOFIA spectroscopy will probe the masses, compositions, and longevity of such fall back disks.

Remnants might also accumulate circumstellar disks when they pass through a dense molecular cloud by Bondi-Hoyle accretion. SOFIA detections or limits on IR emission from hard X-ray sources in molecular clouds can be used to constrain the Galactic population of old stellar remnants left over fro the birth of our Galaxy. Such measurements will provide constrains on the evolution and star formation history of our Galaxy.

Stellar remnants in close, mass-transfer systems produce exotic phenomena such as themicro-quasars (e.g. LSI +61 303, SS430), and the Great Annihilator in the Galactic center. In some cases, the winds and relativistic jets interact with the dense phases of the ISM. IR spectroscopy can reveal the unique signatures of the excitation of the dense ISM by hard X-ray, ?-rays, and relativistic particles.

Destruction of Planetary Systems: When low-mass stars swell into red giants, they will vaporize their planetary systems. The thousand-fold increase in the luminosity of Sun-like stars will a;so evaporate their remnant Kuiper Belt objects and Oort cloud comets, thereby injecting large amounts of water, ammonia, and dust. As the stellar envelope swells, hot Jupiters and terrestrial planets will be consumed and outer gas giants will be greatly heated. SOFIA observations of the nearest red-giants will reveal the ultimate fate of our Solar System through peculiar compositions that reflect those of the disrupted bodies. Planetary destruction may result in local chemical enhancements that might be revealed by spectro-imaging of the closest red-giants.

3.0 The Chemical Evolution of the Universe (Chair: Dan Jaffe)

Observations with SOFIA will provide crucial information about the processes that have enriched the metal content of the universe. The current picture is that H/He rich primordial matter produced by Big Bang nucleosynthesis condensed into galaxies during the epoch of galaxy formation. Since then, nucleosynthesis in stars and stellar explosions has created metals that are returned to the ISM by post main sequence stellar winds and the ejecta produced in the explosions of evolved stars. These materials form the building block of planetary systems, debris disks, and life itself in subsequent generations of stars.

3.1 SOFIA and its Role in Studying The Life Cycle of Dust and Gas

The great strength of SOFIA is the enormous breadth of its capabilities and the flexibility with which those capabilities can be modified and improved. In particular SOFIA has the unique ability to carry out spectroscopy across almost all of the three decades in wavelength between 1 μm and 1 mm. This ability gives SOFIA a significant overarching mission within NASA's goal of understanding the origin of terrestrial planets, planetary systems, and their host stars. This mission is to understand the chemical evolution of solid and gaseous matter from the ejection of heavy elements from evolved stars through the formation of rocky planets and the deposition of water and organic molecules on these bodies.

3.2 From Stellar Death to the Formation of Terrestrial Planets

We understand the basic outlines of the evolution to our present chemical environment, but many of the key mechanisms are only poorly understood. If we wish to understand some of the key steps, we need to address the many unresolved questions about the evolution of gas and dust. IR and submillimeter spectroscopy at both high and moderate resolution are the essential tools for an investigation of the remaining open questions. SOFIA has capabilities across this range that will address the unresolved questions about every stage of the evolutionary process, especially when complemented by results from other ground and space observatories with more narrowly focused strengths.

Arrival of Dust and Heavy Elements in the ISM: Dust made from heavy elements and gas-phase molecules other than H2 play critical roles in our origin. Without these consituents, interstellar gas would not be able to cool to form gravitationally unstable protostellar cores. Without them, the raw materials for planet formation would not be available. This latter point is made with particular force by the strong correlation between metallicity and the likelihood of extrasolar planets (Gonzalez 1997). Heavy elements are produced in stellar interiors and make their way into the interstellar medium by a variety of mechanisms during the last stages of stellar evolution. One goal of SOFIA will be to study the state this “freshly minted” solid and gaseous interstellar matter as it enters into the chain of evolution.

The Transition from Atomic to Molecular Clouds: The gas and dust initially resides in clouds where the dominant constituent, hydrogen, is predominantly atomic. Even when molecular material has formed, a substantial fraction of the dense ISM resides in clouds where ultraviolet photons determine the chemistry and energetics of the gas. Through its resistance to ambipolar diffusion, this material may also play a critical role in regulating star formation.

The Chemical Evolution of Molecular Clouds: In a chemical sense, molecular clouds are not static entities, even before protostellar collapse begins. During the molecular phase, the abundances of the various gas-phase molecules steadily evolve. In the cold, shielded portions of the clouds, dust grains grow significant ice mantles, changing both their own characteristics and, through depletion, the chemical makeup of the gas. These changes set the stage for the formation of stars and planetary systems.

We discuss the evolution of the solid matter and the gaseous matter across this evolutionary path separately. The interaction between the two is critical and we mention it along the way, but differences in observational techniques and physical mechanisms require a separation of the discussion at the level of specific experiments.

3.3 Evolution of Solid Matter

Evolution of Refractory Dust Grains: The cores of dust grains make a curious journey from crystalline to amorphous back to crystalline along there way from late-type stellar atmospheres to protoplanetary disks. The matter emerging into the ISM has a significant fractional content in crystalline material (~5%). Interstellar clouds, on the other hand, have a much lower (<1%) crystalline fraction. In protostellar disks, evidence from IR spectroscopy and from studies of comets indicates that material is somehow annealed and returned to crystalline form. This cycle involves many different chemical and physical processes which are only poorly understood. Understanding this evolutionary history requires a moderate-resolution spectroscopic capability across as broad a range as possible. Broad temperature ranges, optical depth effects, overlapping of broad features, and the presence of a range of dust types in each source, not to mention the contributions in cool sources of ice mantles, make spectroscopy across the range from 8 to 120 μm essential in studying the evolution of refractory material. With SOFIA, we have the ability to measure the shape and depth of solid-state features across this entire range in AGB star envelopes, diffuse interstellar clouds, and dense molecular clouds.

Ices as a Step Toward Protoplanets: While refractory materials dominate the story in the initial evolution of interstellar material, ices play a major role in the later stages. Once the density and column density of molecular clouds grow sufficiently large, many abundant molecules (water, methane, and CO, for example) rapidly form mantles on the refractory grains further depleting the gas of heavy elements and strongly altering the gas-phase chemistry. The whole subsequent chemical history of protostars unfolds with the processed and returned ices as a significant influence. The development of these ices had a strong effect on the present-day chemical state of bodies throughout the solar system. These icy mantles can be studied in transmission against background sources both in cold and moderately warm environments as star formation unfolds. To get a complete picture of the chemical and physical nature of the icy material, we need to use absorption bands throughout the near, mid, and far-IR. It is only with this broad coverage that we can determine compositions and abundances in the face of opacity and temperature differences, as well as confusion with features from refractory constituents or different ices.

PAH's, Energetics, and Ionization Balance: Polycyclic aromatic hydrocarbons are the carriers of a large number of spectroscopic features in the 3-30 μm region. Difference in features show variations in the types of molecules present and in their ionization state. The mid-IR PAH lines are the strongest spectral features in starburst galaxies and these features are prominent in a broad range of Galactic objects. Since SOFIA is able to study these features except in the 14-18 μm range, we will be able to study their behavior along the evolutionary sequence from diffuse clouds to protoplanetary systems.

3.4 Evolution of the Gas Phase

Evolution of Heavy Element Abundances: The dust measurements tell only part of the story of the life-cycle of heavy elements, especially CNO elements. SOFIA's ability to observe a host of IR and far-IR lines of carbon, nitrogen, and oxygen and their molecules in interstellar clouds throughout the Galaxy, in addition to lines of other key elements such as sulfur will greatly improve constraints on the past history of star formation and nucleosynthesis in all parts of the Galaxy. SOFIA's ability to observe both far-IR OI lines and both far-IR OIII lines, in particular will allow us to trace radial variations of oxygen abundance in the Galaxy, along with variations in the carbon and nitrogen gas-phase abundances. In the Galactic Center, elemental abundances derived from interstellar measurements and those derived from measurements of young and massive stars are currently in conflict in some cases by factors of 3-10. The broad range of lines available with SOFIA will help us resolve this problem as part of the broader effort to understand the spatial and temporal evolution of gas-phase enrichment of heavy elements.

Photodissociation Regions and the Structure and Evolution of Dense Gas: Throughout the neutral ISM at low densities, UV photons control the energetics and chemical state of the gas. Even in dense regions, most of the material is in a state where UV photons play a significant role. The partial ionization state of this gas may affect its ability to shed magnetic pressure and collapse. Photodissociation regions therefore may be an important factor in determining the global efficiency of star formation. With its ability to look not only at the major cooling lines of oxygen and carbon but also at Fe and Si lines at 20-40 μm SOFIA will be able to probe the physical conditions in this component of the massive cores where most stars form.

Deuteration as a Critical Test of ISM Evolution: Tracing the abundance of deuterated molecules provides us a means of following the chemical and physical history of dense molecular gas from the onset of the molecular phase through the formation of planets. Deuterium is formed in the Big Bang but is subsequently lost as material is cycled through stars. While the relative abundance of deuterium is very low (1.6x10-5 relative to H), various processes enrich its abundance isotopomers of molecules, sometimes by as much as 13 orders of magnitude. The echoes of this deuteration are seen in the deuterium enhancements in some molecules found in comets. By following patterns of deuteration, one can learn about the chemical evolution of the dense ISM in a way that informs our understanding of the physical history of the gas. Much of the picture of chemical deuteration in dense cores has come from ground-based submillimeter observations. SOFIA, however, has two significant roles to play in completing our understanding of deuterium chemistry.

In the molecular ISM deuterated molecular hydrogen is the dominant reservoir of deuterium. Unfortunately, HD is difficult to observe because of its very small dipole moment. The ground-state transition of HD (at 112 :m, 2.675 THz) will become accessible with SOFIA-CASIMIR (ISO has detected this transition of HD in emission towards Orion at low spectral resolution). Since HD can exist in a variety of regions having different densities and temperatures, high spectral resolution is the only way to be certain of where any HD seen in absorption or emission is located. Studies with a heterodyne instrument on SOFIA will be able to use bright continuum sources many kpc away (e.g. Sgr B2 near the Galactic Center, W49, W51) and probe the HD in the well-known clouds along the line of sight through well resolved absorption features.

The degree of deuteration of molecules in dense environments should begin to drop as the gas warms an less highly deuterated ices sublimate. The dominant species of several of the more interesting molecules (notably acetylene and methanol) have no permanent dipole moment and cannot be observed in the millimeter. With SOFIA-EXES, we have the possibility of observing vibrational bending modes of these species in absorption while simultaneously determining the abundance of the deuterated species along the same lines of sight.

3.5 The Interplay Between Gas and Dust

Deep inside cold and dense molecular cloud cores, atoms and simple molecules accrete onto dust grains. Hydrogenation and oxidation reactions among the accreted species form an icy mantle consisting of simple molecules such as H_2O, CO, CO_2, H_2CO, CH_3OH, CH_4, and NH_3 and their deuterated isotopologues. These molecules can be released into the gas phase of the cold core following a sudden temperature spike due to a cosmic ray hit. They can also be released into the gas upon warming of the dust by a star newly formed in the core. This interaction between gas and grains is thought to be one major route towards molecular complexity in space. Essentially, in the gas phase, all carbon locked up in CO is essentially prevented from participating in organic chemistry but on a grain surface, hydrogenation reactions can activate accreted CO leading to a rich chemistry. In addition, the depletion of the gas phase has a profound influence on the gas phase composition. These profound changes in the gas phase composition are not fully understood.

This chemical interaction between gas and dust has been notoriously difficult to follow observationally. For one, many of the key absorption features of icy molecules occur in IR wavelength regions that are obscured from the ground. In addition, IR spectroscopy of ices probes the conditions along pencil beams in absorption towards embedded or background objects while the gas phase is commonly probed through millimeter transitions in emission in much larger beams. This difference in beam size hampers a direct comparison of the organic inventory of the gas and solid phases.

SOFIA will provide a unique window on the interaction between the gas and solid state of molecular clouds. Specifically, SOFIA is the only observatory that can probe both the gas phase and the solid state H_2O abundance – the main component of interstellar ices - along the same pencil beam through the vibrational modes in the mid-IR. While the ice bands are relatively broad and require only a spectral resolution of ~1000 and hence can be probed by MIRI on JWST, the gas phase ro-vibrational transitions require high spectral resolution (~100,000). SOFIA can perform such studies on bright protostars and probe the cold material in the surrounding molecular cloud. SOFIA is also well suited to study the lattice modes of ices at long wavelengths. In particular, H2O has strong and broad lattice modes at 45 and 60 μm and SOFIA is the only observatory that can probe these modes. In addition, there is circumstantial evidence that part of the gas freezes out in molecular mantles consisting mainly of CO, O_2 and/or N_2. Particularly the latter species can only be probed through their lattice vibrations between 100 and 300 μm. These relatively broad bands require only a spectral resolution of about 30 but a relatively broad wavelength coverage. These lattice vibrations will be in emission and hence will provide a direct handle on the composition of ices on a scale that is comparable to that of gas phase rotational transitions. Finally, freeze out is a run-away process and during the last stages H_2D+ and HD_2+ are the only species left to trace the physical conditions and conditions in the gas phase. The pure rotational transitions of these light hydrides occur in the far-IR/sub-mm.

4.0 Extra-Solar and Solar System Planetary Science (Chair: David Black)

An important and unifying theme that runs through much of space science revolves around life with emphasis on its formation, habitats, and in the case of humanity, some aspects of its long-term safety. Three of the five top-level science objectives in the September 2006 NASA Planetary Roadmap document mention life or humans explicitly, and the other two have associated investigations that involve studies of water, a key aspect of life. A topic that is high priority for the Origins component of NASA'S astronomy program is the search for and characterization of other planetary systems. The early SOFIA science opportunities listed below are chosen because they specifically address the high priority science objectives mentioned above.

4.1 Extra-Solar Planets

Transiting extrasolar planets with mass estimates determined from radial velocity measurements are particularly valuable objects to study. From the planetary astronomy point of view one can estimate their mass, radius, and mean density and search for rings and satellites (e.g. Charbonneau, et al., 2000), search for other planetary objects in the same system by measuring transit timing perturbations (e.g. Holman & Murray, 2005), study atmospheric composition by transmission spectroscopy (e.g. Deming, et al., 2005b), estimate their albedo (e.g. Richardson, et al., 2003) and effective temperature (e.g. Charbonneau, et al., 2005), and even begin to study heat redistribution from atmospheric circulation (Knutson, et al., 2007b).

The radius of a transiting extrasolar planet is best determined during primary minimum (using eclipsing binary star terminology) by means of near-IR observations where the stellar limb darkening is minimal (Snellen & Covino, 2007). On the other hand the stellar limb darkening as a function of wavelength in the optical region can be profitably utilized to constrain the orbital inclination (Knutson, et al., 2007a). Starspots also are more evident in optical data, and observations that span the peak of the stellar blackbody can define the color temperature of spots (Pont, et al., 2007). This suggests that high precision simultaneous multi-wavelength observations at primary minimum would be a very profitable undertaking. Spectrally resolved observations at optical and near-IR wavelengths are also valuable for exploring the atmospheric composition of the extrasolar planet by transmission spectroscopy.

Observations of the occultation of the planet by its star, or secondary minimum, provide information concerning the emission from the planet and its temperature. Again, these observations can be photometric or spectroscopic. Thermal observations as a function of phase angle help constrain the temperature of the planet as a function of substellar longitude, revealing evidence of heat redistribution in the planetary atmosphere (Knutson, et al., 2007b). Timing of primary and secondary minima constrains the eccentricity of the planetary orbit.

SOFIA has the capability to carry out the observations just described. HIPO is a high-speed optical imaging photometer capable of observing bright objects for long periods of time with almost 100% observing efficiency simultaneously at two wavelengths between the atmospheric cutoff at 0.3 μm and the silicon detector cutoff at about 1 μm. FLITECAM is an InSb imager/spectrometer with similar photometric capabilities at a single wavelength as well as grism spectroscopy within the 1-5 μm wavelength range. In fact these two instruments can be so-mounted, providing high precision simultaneous observations at three wavelengths (Dunham, et al., 2007), ideal for observations during primary minimum. Optical data are not needed for observations of secondary minimum, so these observations would be done with FLITECAM mounted alone.

For a given object the duration of the observing leg should ideally be approximately 3 times the transit duration to insure that the out-of-transit brightness level is well measured. Depending on the object this can be 5 hours or longer. SOFIA can easily support long observing legs on flights that involve deployment to remote locations. A special flight plan that follows a small circle at approximately 60 degrees north latitude can keep a given object on the meridian indefinitely!

Other NASA assets that currently contribute to the field of transiting extrasolar planets include the Hubble Space Telescope (following the upcoming servicing mission) the Spitzer Space Telescope, and ground-based assets such as the IRTF and the NASA share of the Keck telescopes. The Kepler mission will provide a wealth of data on stars in its field of view beginning in early 2009. On a much smaller scale the Transiting Exoplanet Survey Satellite (TESS), currently a pending SMEX proposal, will carry out a comprehensive full sky search for the brightest, most astrophysically productive, transiting systems if it is selected for flight. Finally, the James Webb Space Telescope will have a profound impact on the field once it is launched and successfully operating.

Spitzer, while being very successful in observing thermal emission from extrasolar planets (e.g. Deming, et al., 2005a, Charbonneau, et al., 2005, and Knutson, et al., 2007b), lacks capability in the K band. The 3.6 and 4.5 μm IRAC bands (Fazio, et al., 2004) that will continue to be usable during the warm Spitzer mission overlap the L band minimally. The reader may recall that exoplanet atmospheric models suggest that the K and L bands are of particular merit. Of course Spitzer will have no spectroscopic capability during the warm mission. SOFIA can fill the spectroscopic need as well as provide observations in the K and L bands. K band will be of particular importance for SOFIA due to the low thermal background of the telescope at stratospheric temperature.

HST has a demonstrated capability for excellent work at optical wavelengths (e.g. Knutson, et al., 2007a), but cannot observe a full transit owing to its orbital period. It also lacks IR capability so simultaneous optical and IR observations are not possible without calling in another resource. SOFIA can provide simultaneous optical and IR data and could also provide high quality complementary data to combine with HST observations.

The Kepler mission is primarily targeted toward discovery of terrestrial planets (Borucki, et al., 2007) but will also discover a substantial number of "hot Jupiter" planets. Some of the Kepler discoveries will be excellent targets for SOFIA and other facilities; indeed, we anticipate observing a limited number of Kepler targets with SOFIA.

JWST, once operating, will likely become the pre-eminent facility for near-IR observations of transiting extrasolar planets. Its location in a thermally stable L2 orbit, large aperture, cold telescope, and instrument complement all indicate extraordinary sensitivity.

4.2 Studies of Solar System Objects

Studies of solar system objects and phenomena are valuable in that they provide an opportunity to gain insight into the formation and behavior of similar objects and phenomena around other stars. Moreover, in some cases this opportunity is unique owing to "ground truth' data available via complementary spacecraft missions. Two examples of this synergistic relationship could be realized with early SOFIA science, viz., studies of cometary dust and studies of outer planet atmospheres.

It is clear that observations of comets in the 16-45 μm region provide our most direct means of determining the nature of cometary grains. While ground-based telescopes provide the greatest degree of flexibility in scheduling, the high opacity in the 16-45 μm region makes them unsuitable for this analysis. The Spitzer Space Telescope, is superior in this regard, but it is not expected to be operational beyond 2009 and it cannot observe objects along sight lines close to the Sun. Because comets are brightest when they are physically close to the Sun, most comets cannot be observed with Spitzer when they are brightest. Similarly, the restriction in the anti-solar direction is 120º solar elongation, which prevents observations when the comets are at opposition, when they are often closest to the telescope, and have the best angular resolution in km. SOFIA is clearly the best platform to perform this sort of science. Understanding this source of circumstellar debris, along with other contributors to the zodiacal cloud of our planetary system, will allow us to draw sounder conclusions from remote analysis of circumstellar debris disks found in abundance around other stars.

Studies of the Sun have played a critical role in understanding other stars. It is to be expected that in a similar vein studies of the outer planets in our Solar System will yield insight into processes and conditions that occur among the diverse sample of giant planets around other stars. The now substantial number of giant planetary like objects found revolving around other stars adds to the significance of studies of Jupiter, Saturn, Uranus, and Neptune as surrogates for their more distant cousins.

Some 65 million years ago, a 10 km body hit the Earth and caused the extinction of the dinosaurs. The U.S. Congress has established a requirement that 90% of the potential Earth-impacting asteroids larger than 140 meters be identified by the year 2020. In this way, potential hazards can be identified, and mitigation plans defined, if necessary. These potentially threatening asteroids have been named Potentially Hazardous Asteroids (PHAs), and generally fall within the dynamical category of Near Earth Object (NEOs). PHAs are defined as bodies larger than 140 meters that will pass within 0.05 AU of the Earth's orbit, and NEOs are all bodies whose orbits pass within a few tenths of an AU of the Earth's orbit. These bodies are of specific interest to humans. Characterizing potential threats to life on Earth carries an almost unimaginably high value.

Obtaining a few photometric points of the FIR-thermal spectra of asteroids gives the possibility to estimate their size and albedo. FORCAST (Faint Object InfraRed CAmera for the SOFIA Telescope), a mid-IR two-channel instrument is the perfect instrument for this science case. Based on the sensitivity limits described on the SOFIA webpage for FORCAST: 20 mJy, 15 mJy, and 60 mJy at 11, 20, 33 µm respectively, An estimate of the minimum diameter for an NEA to be detected with a S/N=4 in 15 min integration time is shown below. Specifically, an NEA as small as 0.7 km, so H=18 with Av = 0.2 can be observed with this instrument. A fifth of the now known NEA population (~1000 asteroids) can be studied with FORCAST. Of interest also are the physical properties of these potential Earth impactors. We estimate that 180 NEAs with H<16 can be observed with the EXES instrument on SOFIA

5.0 Extragalactic Science (Chair: Danny Dale)

Early extragalactic opportunities that take advantage of SOFIA's superior angular resolution and high resolution spectroscopy include:

5.1 Interstellar Medium

The long wavelength baseline and high angular and spectral resolution capabilities offered by SOFIA permit many avenues to characterizing the physical conditions within the interstellar medium of galaxies. Large-scale spectral imaging of a suite of mid- and far-IR lines (e.g., [OI]63µm and 146µm, [CII]158µm, [SiII]35µm, [OIII]88µm and 52µm, [NII]122µm and 205µm, [NIII]57µm, H_2, and high level transitions of CO), previously unattainable by a single mission, constrain the properties of the neutral and ionized gas (e.g., density, temperature, mass), and the strength (numbers of stars) and hardness (most massive stars) of the interstellar radiation fields. The high spectral resolution instruments onboard SOFIA will allow us to characterize PAH composition, central wavelengths of emission, feature widths, ratios, etc.

Despite numerous theoretical studies that suggest the strong impacts of galactic dynamics on the evolution of the ISM (e.g., Wada & Norman 1999; Kim et al. 2003; Chakrabarti et al. 2003; Wada & Koda 2004), surprisingly little observational progress has been made. In particular, Spitzer spectral observations have been devoted almost entirely to star-forming regions or nuclear regions (e.g., Roussel et al. 2007), not on global dynamics and the associated evolution of the ISM. Ground-based interferometric maps of CO coupled with high spectral-resolution H_2 maps from SOFIA, covering large enough areas in nearby galaxies such that they encompass nuclear, arm, and inter-arm regions, will help to address several outstanding questions. Is interstellar turbulence driven more by star formation or galactic dynamics? Do molecular clouds form in spiral arms or between them? How does the ratio of warm-to-cold molecular gas differ between different environments within galaxies? The high spectral resolution capabilities afforded by SOFIA will be particularly important in disentangling the molecular hydrogen line emission from the polycyclic aromatic hydrocarbon features.

The unique imaging capabilities will enable an inventory of extended cold dust in a variety of galaxies, dust that can easily dominate the dust mass. For example, the dust in elliptical galaxies ranges from being fully accounted for by stellar mass loss to huge excesses that can only be explained by significant galaxy mergers in the past. How much extended cold dust is there in galaxies? What is the provenance of extragalactic extended cold dust: mergers, stellar evolution, or AGN activity (Temi et al. 2007)? For many galaxies we expect that SOFIA will resolve diffuse radial far-IR plumes from extended, excess dust that has been buoyantly transported from the galactic core. Alternatively, if this diffuse dust has been deposited behind merging galaxies, SOFIA will reveal orbit-like far-IR patterns. Regardless of the interpretation, the short ~10^7 yr dust lifetime will translate these observations into interesting and important new information. If AGN feedback dominates, the timescale between central heating events and the time-averaged AGN power can be estimated from the improved statistics of a large sample of ellipticals with and without excess, extended far-IR emission. For the merger hypothesis, the statistics of far-IR fluxes can determine the current merger rate between ellipticals and gas-rich galaxies.

5.2 Star Formation

Since IR wavelengths are far less susceptible to the effects of extinction than the UV/optical, the IR offers an important regime for accurately calibrating star formation indicators (e.g., Calzetti et al. 2007), particularly for extremely dusty systems like ULIRGs that power much of the cosmic star formation rate at intermediate redshifts. The [CII]158µm line is a likely candidate for measuring the star formation rate for high redshift galaxies using submillimeter/millimeter observatories such as SOFIA, ALMA, and CCAT. However, from the sample of ULIRGs and distant QSOs so far investigated, it appears that the [CII]158μm line shows an increasing deficiency with respect to the bolometric IR radiation for more luminous galaxies like ULIRGs (Crawford et al. 1985; Stacey et al. 1991; Malhotra et al. 2001; Luhman et al. 2003; Verma et al. 2005). It is important to establish how reliably the [CII]158μm line traces star formation, and how its reliability depends on environment and evolves with redshift. SOFIA can not only follow-up high redshift detections of C+ with its full suite of diagnostics at other wavelengths, but its superior angular resolution for resolved nearby galaxies will enable detailed studies of the environmental dependencies of [CII]158μm as a star formation rate indicator..

5.3 Cosmic Infrared Background

The cosmic spectral energy distribution is now well measured at HST-WFPC2/NICMOS and Spitzer-IRAC/MIPS wavelengths. A stacking analysis of deep SOFIA-HAWC/FORCAST imaging will help to fill the gaps and extend our knowledge of the cosmic background to longer wavelengths. In addition, surveys by SCUBA2, BOLOCAM, and Herschel-SPIRE and other facilities like APEX and ALMA will detect many submillimeter sources, the properties of which can be studied in detail with follow-up diagnostic observations by SOFIA (SEDs, redshifts, luminosities, stellar masses, density, nuclear activity). Planck data can also be probed with follow-up observations by SOFIA. Planck will detect all-sky fluctuations of the Cosmic Submillimeter Background in a ~5 arcmin beam. SOFIA can follow-up some of the most intriguing fluctuations and study these large structures, potentially at large redshift.

5.4 Nuclear Activity

The fueling of black holes that occurs in active galactic nuclei (AGN) is fundamental to the evolution of galaxies. AGN themselves are largely explained in the context of a unified theory, by which a geometrically and optically thick torus of gas and dust obscures the AGN central engine from some lines of sight, leading to a range of observed properties/classifications. Whilst fundamental to unified theories, the torus remains difficult to image directly at optical/IR wavelengths (accomplished for at most three objects) and hence the torus properties remain uncertain. Accounting for the torus is essential to solve fundamental problems that require quantifying black hole growth over cosmic time and obtaining an accurate census of black holes. A detailed understanding of the torus and AGN activity will allow us to understand the fueling process and its relationship to (or even creation of) the torus, the interaction with the host galaxy, and dust chemistry in other galaxies. The next generation of telescopes will probe the distant universe, where the relationship between the host galaxy, black hole and AGN evolution may be evident. Hence it is crucial to understand our local universe in detail in order to interpret high-redshift observations that are far more challenging in both faintness and spatial resolution.

Ground-based observations at 10-20μm from 8m class telescopes had been expected to directly resolve the torus emission, separate from the surrounding galactic dust and stars. However, it has become clear from both recent observations (Packham et al. 2005; Perlman et al. 2001;

Whysong & Antonucci 2004) and new (Nenkova et al. 2002), complex 'clumpy' torus models that the emergent emission from the torus at these wavelengths remains unresolved, as the dominant amount of torus material is compact (< a few pc). Nevertheless, progress is possible now using the combination of the high spatial resolution ground-based observations in the 10µm region and the large wavelength coverage of Spitzer to disentangle the complex interplay of galactic dust, PAH, and synchrotron radiation from the torus signature. Utilizing a full 7 to ~40µm bandpass, careful investigation has tightly constrained the torus properties and advanced the models (Perlman et al. 2007). Despite these gains, the relatively poor resolution of Spitzer still leaves significant ambiguity from the contaminating sources. SOFIA's larger aperture will improve resolution by a factor of ~3, which should effectively isolate the torus emission directly to reveal its spectral turnover around 30µm. This separation from the confusion of nuclear star formation is essential to determine the intrinsic broad-band spectral energy distribution of AGNs, extending to the far-IR. Moreover, the possibility to observe at a variety of spectral resolutions and in modes that were unavailable on Spitzer (i.e. polarimetry in future instruments or upgrades) makes SOFIA the ideal platform to address these fundamental astrophysical questions. Such studies hold the promise of fully characterizing AGN activity, the torus properties, and possibly even torus creation.

6.0 Community Knowledge Base (CKB) Observing Programs (Chair: Matt Greenhouse)

Over the past decade, science utilization policies for NASA general astrophysics observatories have recognized a need to enable acquisition of coherent homogeneous data sets that are of long term value and applicable to wide areas of astronomical research. Examples include the Spitzer Legacy and HST Treasury programs. We refer to this general pathway for enabling community access to NASA observatory facilities through purpose-built coherent archives as Community Knowledge Base (CKB) observing programs.

An optimally implemented CKB program consists of projects that are competitively selected large coherent investigations whose scientific goals can not be met by a number of smaller uncoordinated General Observer (GO) program investigations. Data collected under the CKB program are non-proprietary and immediately enter an open community archive that is administered and supported by the mission science operations center.

Observing projects appropriate to a CKB program yield data that will be of both general and lasting importance to the broad astronomical community and of immediate utility in motivating and planning follow-on General Observing program investigations. A vibrant CKB program can dramatically increase mission science productivity by using the existing infrastructure for archival research as a process for enabling primary mission research. The CKB program provides a tool to enable highly effective science community access by treating the mission data archive as a primary research tool with content that are of deliberate scientific design rather than as an incoherent repository for data assets of uncoordinated proprietary GO projects.

Observing projects that are designed to populate the mission CKB archive are solicited under CKB observing proposal calls which have mission time allocations appropriate to enabling large projects. Selections are made using the normal Time Allocation Committee process. Experience garnered through Spitzer and HST CKP efforts is that the science community strongly prefers each CKB proposal call to be open to all science topics that can be addressed by the flight asset in question.

Observing projects that are appropriate for a mission CKB program can be distinguished from GO program projects by the following three criteria: 1) the project is a large, coherent investigation whose scientific goals can not be met by a number of smaller, uncoordinated projects, 2) the data will be of both general and lasting importance to the broad astronomical community and of immediate utility in motivating and planning follow-on GO investigations, and 3) the data (unprocessed, fully processed, and at intermediate steps in processing) will be placed in a public data base immediately and with no proprietary period. CKB and GO programs can also be distinguished in terms of their direct deliverables to NASA. The GO program deliverable is publicly disseminated scientific results obtained using proprietary data. In contrast, the direct deliverable of the CKB program is a public data base from which scientific results are obtained and disseminated by the general astronomical community and CKB project teams.

Ongoing allocation of substantial mission observing time to CKB programs reflects a maturation of the science utilization policy for general astrophysics space observatories. A well administered CKB program can yield archival research productivity that far outlasts the mission flight operations phase. Data under this program enter world-wide science community grasp immediately and can substantially increase the cadence of discovery during mission operations by removing the retarding effect of propitiatory periods.

The CKB program yields an open mission archive with content that is of deliberate design by the science community. This open and purpose-built coherent archive approach can substantially increase early science return on mission investment by enabling theoretical and other research communities to access data produced by the flight asset without having to plan engineering and technical details associated with acquisition of the data.

6.1 Application of CKB programs to the SOFIA mission

The goals of a SOFIA CKB program would be to enable community use of SOFIA for acquisition of large coherent observations (such as surveys of a large class of object or wide ranging panchromatic spectroscopic, imaging, and temporal observations of a small set objects), and to enable broad and immediate community access to SOFIA survey data for primary research.

An air-borne CKB project would span a large number of flights. Hence, it will require a stable flight instrument configuration over the data acquisition period and a fully supported ground system for the configuration in question and resulting archive. As a consequence, we recommend that implementation of a CKB program on SOFIA be deferred to the start of normal science operations. However, due to the highly complex nature of airborne observing, we note that CKB programs may provide the most effective means by which science productivity of SOFIA is achieved by the broad astronomical community.

The initial science instrument program for SOFIA emphasized two classes of instrumentation: PI class visitor instruments and facility class instruments. A CKB program would be applicable to the latter class for which one can expect well defined stable observing modes and science operations center provision of: data pipeline processing, data analysis tools, consistent high quality observing proposal support and archival research support.

6.2 Issues Related to the Definition of SOFIA CKB Programs

CKB observing proposal calls: A CKB program solicitation would be a General Observer (GO) proposal call designed to enable large, coherent investigations whose scientific goals can not be met by a number of smaller uncoordinated GO program investigations.

Science enabled by and appropriate for SOFIA CKB observing programs: The science enabled by SOFIA CKB observing programs would require a large allocation of observing time to a given GO project team (as opposed to a given topic). Experience shows that a typical TAC process deals with such proposals well, if and only if there is a specific program allocation for them. The core objective of creating an allocation for CKB projects is to enable observers to tackle science problems that necessitate proposing for large blocks of time. Since CKB project teams are allocated a large fraction of the community's observing time, a CKB program would seek projects that yield data that will be of both general and lasting importance to the broad astronomical community and of immediate utility in motivating and planning follow-on research.

The solicitation of specific science topics in a CKB program proposal call: Experience on other NASA missions has shown that the community strongly prefers CKB proposal calls to be open to all science topics and all scientists.

Disposition of data obtained through CKB projects: In keeping with the precedents established by similar programs on previous and existing NASA missions, CKB project PIs would be performing a science enabling service to the community in which all project data products enter a Science Operations Center (SOC) administered public archive as quickly as technically feasible.

Science instruments are appropriate for CKB project use: Experience on other missions suggests that instruments used in CKB programs should have stable and well characterized observing modes, mature reduction pipelines and analysis tools, and a high degree of expert technical support through a Science Center to the CKB PI team and archival research teams.

SOFIA CKB projects and cience instrument technical upgrades: Coordinated management of observatory scheduling and maintenance/upgrade activities is required to enable execution of GO programs that are selected on an annual cycle. CKB projects do not present a unique observatory management challenge in this regard.

Implementation of a SOFIA CKB Program: The baseline science utilization policy for SOFIA does not currently include a CKB program element (http://www.sofia.usra.edu/Science/observing/sci_observing.html). The SOFIA Community Task Force is currently seeking user community input on desirability of a CKB program for SOFIA.

7.0 summary and Conclusions

8.0 Appendices

Appendix A: Table of Missions and their Scientific Capabilities

Appendix B: References

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