An Implementation Concept for the ASPIRE Mission.

W. D. Deininger* (wdeining@ball.com), W. Purcell,* P. Atcheson,*G. Mills,* S. A Sandford,** R. P. Hanel,** M. McKelvey,** and R. McMurray**

*Ball Aerospace & Technologies Corp. (BATC)
P. O. Box 1062
Boulder, CO, USA 80306-1062

**NASA Ames Research Center
Moffett Field, CA, USA 94035

Abstract—The Astrobiology Space Infrared Explorer (ASPIRE) is a Probe-class mission concept developed as part of NASA's Astrophysics Strategic Mission Concept studies. [1] [2] ASPIRE uses infrared spectroscopy to explore the identity, abundance, and distribution of molecules, particularly those of astrobiological importance throughout the Universe. ASPIRE's observational program is focused on investigating the evolution of ices and organics in all phases of the lifecycle of carbon in the universe, from stellar birth through stellar death while also addressing the role of silicates and gas-phase materials in interstellar organic chemistry. ASPIRE achieves these goals using a *Spitzer*-derived, cryogenically-cooled, 1-m-class telescope in an Earth drift-away heliocentric orbit, armed with a suite of infrared spectrometers operating in the 2.5-36 micron wavelength region supported by a *Kepler*-based spacecraft bus. This paper summarizes the results of the ASPIRE Origins Probe Mission Concept Study while focusing on its high heritage mission implementation.

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1. INTRODUCTION

Astrobiology has two principal goals: 1) to learn how life began and evolved on Earth, and 2) to establish whether life exists elsewhere in the universe. Understanding the cosmic evolution of molecules that carry the elements C, H, O, and N is central to this quest. The history of these elements is complex and tied to the cyclic process whereby these elements are ejected into the diffuse interstellar medium (ISM) by dying stars, gathered into dense clouds and formed into the next generation of stars and planetary systems (Figure 1). Each stage in this cycle entails chemical alteration of gas- and solid-state species by a diverse set of astrophysical processes: hocks, stellar winds, radiation processing by photons and particles, gas-phase neutral and ion chemistry, accretion, and grain surface reactions. These processes create new species, destroy old ones, cause isotopic enrichments, shuffle elements between chemical compounds, and drive the universe to greater molecular complexity. Understanding the inventory and evolution of cosmic organics requires the study of a broad sample of well chosen objects that characterize all stages of this evolutionary path. This includes study of materials found in our Solar System and in exoplanets, which serve to link interstellar materials to those delivered to planets. We also need to study other galaxies to probe, on a universal scale, the role variables such as age, galactic type, and metallicity, play in organic evolution through cosmic time.

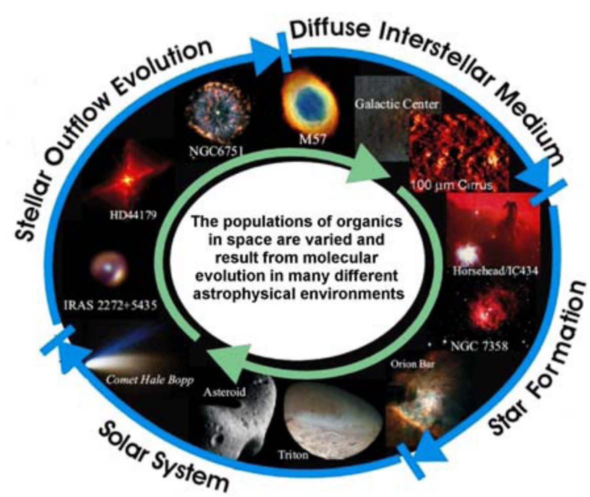

***Figure 1** – Organics in space vary with location and represent products of multiple astrophysical and astrochemical processes.*

Previous telescopic observations provide a glimpse of the rich variety of molecular materials in space – gas-phase

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molecules, mixed molecular ices, polycyclic aromatic hydrocarbons (PAHs), and refractory aliphatic hydrocarbons have all been detected [1-4]. Lab studies show that some of these materials can form species of astrobiological interest under astrophysical conditions [5]. Organics exist in many Solar System objects [6], and some of these have presolar origins. Recent studies have shown that organic compounds are also common in other galaxies [7] and that molecules can be detected on exoplanets [8]. These observations provide a hint of the rich insights to be gained from the study of extraterrestrial prebiotic materials.

However, we currently have an incomplete understanding of the inventory and inter-relationships of these materials due to limited data. Progress awaits the collection of a comprehensive and uniform spectral database from a well-planned target population that spans all objects of interest. The Astrobiology Space Infrared Explorer (ASPIRE) is a Probe-class mission concept developed as part of NASA's Astrophysics Strategic Mission Concept studies to provide this comprehensive and uniform spectral database. This paper summarizes the results of the ASPIRE Origins Probe Mission Concept Study while focusing on its high-heritage mission implementation. The ASPIRE spacecraft derives from the proven *Kepler* spacecraft [9-17] (Figure 2), while the telescope, cryostat and spectrometers draw heavily from *Spitzer* [18-19] (Figure 3).

***Figure 2** – Fully Integrated Kepler Observatory prior to shipment to launch site.*

2. Science Goals and Objectives

An effective study of cosmic organics requires their comprehensive study in all the cosmic environments through which they cycle in our, and other, galaxies. The elements of such a comprehensive study are discussed in the references [37-48]. Here we provide a summary of the scientific arguments for the ASPIRE mission.

***Figure 3** – Spitzer CTA prior to protoflight environmental testing.*

Molecules Within Our Galaxy

Molecules within our galaxy participate in a continuous cyclic process that spans a wide range of astrophysical environments. Each stage in this cycle, and transitions between them, involve a unique set of conditions and processes that form, destroy, and modify different molecular species.

Stellar Outflows—The life cycle of organic materials in space begins with the late stages of stellar evolution, where organic molecules are made in the stellar winds from extreme carbon stars [20]. Limited IR spectra of C-rich objects suggest a great diversity of compounds is present (Figure 4). The origin of this diversity may reside in the varied physical conditions of these objects or in the rapid evolution of these objects and their ejecta.

The Diffuse Interstellar Medium (DISM)—Stellar ejecta mix with material already present in the DISM. DISM materials appear to include non-uniformly distributed aliphatic hydrocarbons attached to aromatics [2,21] and gas-phase PAHs [22,23]. These are an integral part of the cycle of interstellar organics since they contain the end products of stellar outflows and feed the creation of dense clouds.

Dense Molecular Clouds, Star Formation Regions, and Young Stellar Objects—Independent of their formation sites, cosmic organics must pass through the molecular cloud phase to be incorporated into new stellar and planetary systems. Dense molecular clouds, and the young stellar objects (YSO) within them, show a plethora of absorption and emission features due to mixed-molecular ices and molecular gases [24,25] the processing of which makes many new molecules of astrophysical and astrobiological relevance [5,26].

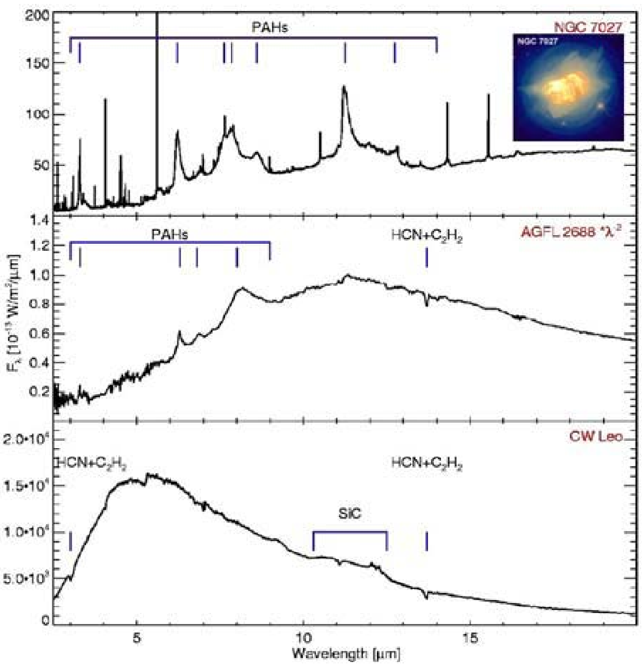


Figure 4 *– IR spectra of C-rich objects show a rich diversity of compounds injected into the ISM and illustrate chemical evolution as the central star evolves from the AGB (CW Leo) through the PPN phase (GL 2688) to the PN phase (NGC 7027) [22].*

While available data hint at considerable evolutionary complexity, the chemistry of dense clouds and star forming regions is currently very incomplete, particularly for solar-type protostars and the quiescent portions of clouds, and the interaction of the gas and solid phases in these clouds.

Molecules in Planets

A central issue to understanding cosmic organics is determining if they seed planets.

Organics in the Solar System—Solar System (SS) bodies like asteroids and comets carry organics that preserve original interstellar and protosolar material [27,28]. Understanding the origin and types of organics and volatiles (particularly H_2O) found in SS bodies permits the study of prebiotic organic chemistry in a planetary setting. The spectra of comets, asteroids, the surfaces of planets and satellites also provide a comparison of SS materials in YSOs, the debris disks around other stars, and exoplanets, thereby aiding our understanding of these systems in a wider context.

Molecules on Exoplanets—The study of exoplanets has emerged as one of the most exciting new areas in modern astronomy. A few of the currently known exoplanets are just now beginning to be spectrally characterized (Figure 5) [8,29,30] and this area is ripe for further progress. Using methods proven with the *Spitzer* Space Telescope [8,30], future IR telescopes will be able to study non-transiting super earths orbiting nearby M stars, search for changes in exoplanet conditions over time, and produce many exciting discoveries.

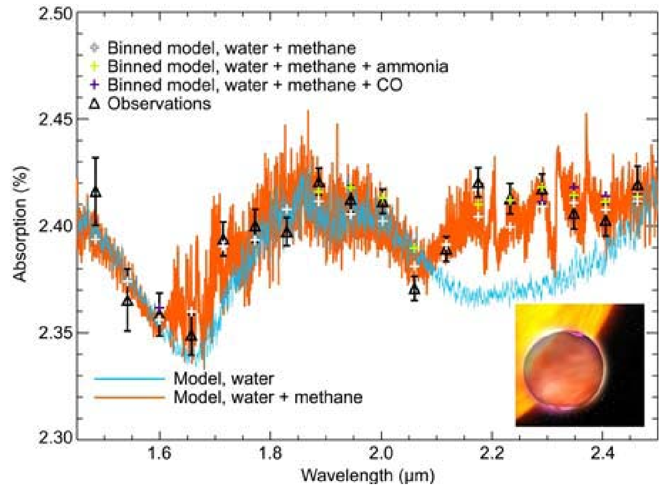


Figure 5 – *A comparison of primary eclipse spectra of HD 189733b (black points) with simulated water (blue) and water+methane (orange) absorption. Both water and methane appear to be present (see [8b]).*

Molecules in Other Galaxies

Observations of sites in our galaxy provide good views of individual environments, but do not explore the range of conditions that exist in galaxies in general. For this, one needs to study the gas and dust found in other galaxies.

'Local' Galaxies—Other galaxies contain materials like the PAHs, aliphatic hydrocarbons, ices, and silicates seen in our galaxy (Figure 6a), but different galaxies display very different IR spectra [31] and current data are restricted in sensitivity, spectral coverage, and/or spectral resolution. Understanding the relationship of organics to galactic age, UV flux, metallicity, energetics, etc. will require a systematic study of other galaxies, including low metallicity dwarf, elliptical, disk, starburst, and ultraluminous IR galaxies, and galaxies with active nuclei.

Distant Galaxies—A remarkable result from *Spitzer* has been the detection of organic spectral signatures in distant galaxies similar to those in our own galaxy (Figure 6b). Strong silicate absorption features have now been measured [32] in 17 ultra- and hyperluminous galaxies with redshifts between z=1.6 and z=2.7. These observations represent a first step towards tracing the abundance and character of astrobiological materials with cosmic time, but a more comprehensive set of data are needed from distant galaxies to understand the nature of solid state and gaseous prebiotic reservoirs and their interrelation at earlier epochs and connect them with the present.

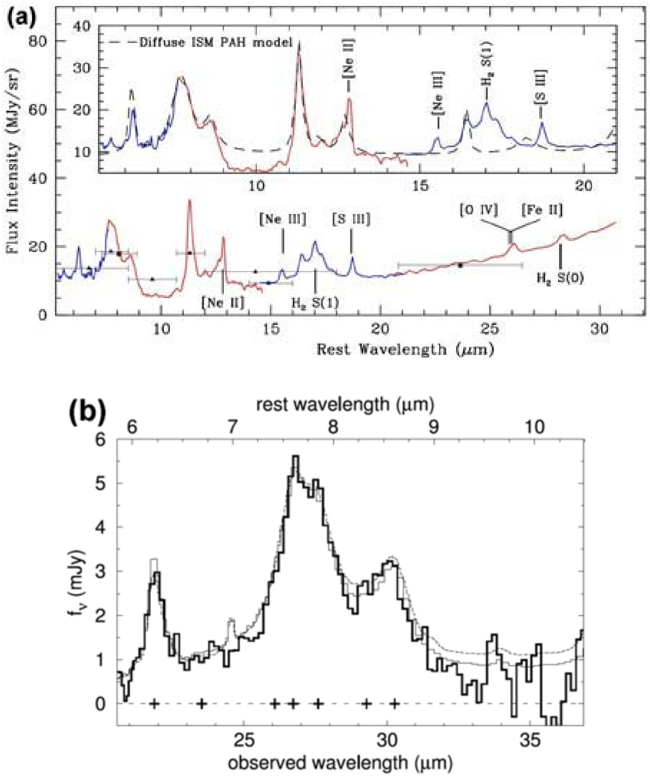


Figure 6 – *(a) 3.5-35 μm spectra of NGC7331 are dominated by PAH features [33]. (b) Spectrum of z=2.516 lensed source SMM J163554.2+661225 (thick solid line) with spectra of starburst galaxy NGC 2798 (thin solid line) and the average of 13 starburst galaxies (thin dashed line). Crosses show known PAH features redshifted from the 5-10 μm region. (see [34] and references therein).*

The measurement of spectral features of both gas and solid materials requires the use of different spectral resolutions. Resolutions of $\lambda/\Delta\lambda \sim$ 1000-3000 are ideal for studying solids, while resolutions of $\lambda/\Delta\lambda \sim$ 25,000 are more appropriate for measuring the individual rotation lines of gas phase species.

3. The Power of IR Spectroscopy

Organics and volatiles reside in both the gas and solid states in many environments of interest, and these materials are in constant interaction. Thus, a comprehensive study of these materials and their inter-relationships requires measurement of both gaseous and solid molecular materials on the same lines-of-sight. Spectral observations in the infrared between 2.5 – 36 μm are ideal for this purpose - this range spans the fundamental vibrations of virtually all molecules, especially those made of C, H, N, and O (Figure 7).

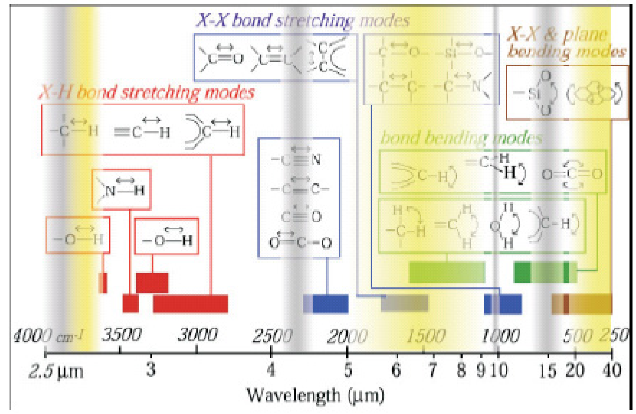


Figure 7 *– The 2.5-40 μm spectral range is ideal for detecting and identifying both gas and solid state molecules. This region can only be fully observed from space – the shaded sections represent regions blocked by atmospheric H_2O (yellow), and O_3 and CO_2 (gray)*

This spectral range has the advantage that it also spans the positions of key isotopic species of C, N, O, and H. Of particular interest is deuterium (D). The interstellar processes that make complex organic species are also expected to yield products that are highly enriched in D [35], with the extent and molecular positioning of the enrichment providing key insights into the chemical processes involved. High D/H ratios in meteoritic organics [36] and the elevated (relative to cosmic) terrestrial D/H ratio suggest that both our Solar System as a whole, and the Earth itself, received a significant portion of these D-enriched materials. Thus, D is a tracer of interstellar chemical processes that can serve as a tool for studying the cosmic evolution of organics and their delivery to planets.

Tracing D also has cosmological significance. D was formed in the aftermath of the Big Bang at an abundance directly related to baryon density. The present abundance of D is thus an important measure of cosmic microwave background (CMB) results. Measurements of high-redshift D/H values are in good agreement with CMB-derived values, but D/H measured in H and H_2 in our own galaxy show large variations difficult to explain by astration. Such variations may be due to the chemical fractionation of D from H mentioned above. Thus, tracing the molecular distribution of D in the local universe provides a means of studying the astrochemical processes that form organics in space and an independent, complementary test of CMB.

4. Leading Up To ASPIRE

Since 2000, mission concepts for a suite of spaceborne observatories have been developed to provide the infrared spectral capabilities needed to carry out the important studies outlined above and are detailed in the literature [37-48]. These mission concepts have been designed to optimize their performance while fitting within the resources available for different NASA space mission programs. The initial mission concept was the Astrobiology Explorer (ABE), which was submitted to NASA in 2001 as a Mid-sized Explorer (MIDEX) mission. This concept was selected for continued Phase A studies, but has yet to be selected for flight. The ABE design has since been continuously matured through funding from various sources, including NASA's Astrobiology Science and Technology Instrument Development (ASTID) Program. In 2004, a more capable version of ABE called ASPIRE was proposed and selected as one of the missions studied under NASA's Origins Science Mission Concept Studies Program. This mission has been further matured under the Astrophysics Strategic Mission Concept Study Program. A third variant mission concept, called the Deuterium Explorer (DEX), suitable for flight as a Small Explorer (SMEX) class mission is also under development. This mission is similar to ABE but focuses on only a portion of ABE's scientific activities.

These three IR spectroscopy missions [37-48] all focus on detection and identification of molecules in space, and they share many scientific and design elements. All three concepts are currently very mature, none of them require prior technology development, and all three are ready for selection for flight. In the material that follows we will concentrate on ASPIRE, the most capable of the three missions.

5. ASPIRE SCIENCE REQUIREMENTS

ASPIRE addresses the questions (1) "Where do we come from?" and (2) "Are we alone?" as outlined in NASA's Origins Program. ASPIRE uses infrared spectroscopy to explore the identity, abundance, and distribution of molecules of astrobiological importance throughout the Universe. ASPIRE's observational program is focused on investigating the evolution of ice and organics in all phases of the lifecycle of carbon in the universe, from stellar birth through stellar death and exogenous delivery of these compounds to planetary systems while also addressing the role of silicates and gas-phase materials in interstellar organic chemistry. Specifically, ASPIRE searches for spectral signatures from organics including: alkanes, alkenes, aromatics, ethers, alcohols, aldehydes, ketones, and nitriles, and trace, key gas phase species such as H_2O, OH, and H_2. The target lists are chosen to observe statistically significant samples of objects of varied types to achieve the science objectives.

ASPIRE's scientific goals are met using infrared spectral measurements organized into key tasks which build on earlier studies. An observatory and study plan capable of successfully pursuing these scientific tasks must meet a number of direct scientific and derived measurement requirements (spatial and spectral resolution, imaging, sensitivity, pointing accuracy, stability, and tracking, etc.). The principal requirements are summarized in Table 1.

***Table 1** – ASPIRE Science Requirements Are Well-Defined.*

Scientific Requirement	Spectra of Solids	Spectra of Gasses
Wavelength Coverage (μm)	2.5 - 36 (no gaps)	3.1 - 17.5 (selective gaps)
Deuterium	3.0 - 5.0	3.1 - 5.0
Spectral Resolution (λ/Δλ)	≥2,500 (2.5 - 20 μm) ≥900 (20 - 36 μm)	≥25,000
Signal-to-Noise	10 - 500	100
Deuterium	300 - 500 (3.0 - 5.0 μm)	301 - 500 (4.0 - 5.0 μm)
Required Sensitivity	Continuum Sensitivity (mly) 1σ, 1000 s	Line Sensitivity (W/m^2) 1σ, 1000 s
2.5 μm 5.0 μm 10 μm 20 μm 36 μm	0.10 0.16 0.28 0.14 0.14	4×10^{-19} 4×10^{-19}
Deuterium (5.0 μm)	0.12	3×10^{-20} (10σ, 10,000 s)
Minimum Surface Brightness	10^6 Jy/str @ 10 μm	N/A
Brightest Object (without saturation)	350 40,000 10,000 450,000	N/A
Photometric Stability (pixel-to-pixel)	Window -- 15% Pixel-to-Pixel -- 2%	Baseline -- 15% Absolute line strength -- 5%
Number of Objects	>3,000 (shared across tasks)	>3,000 (shared across tasks)
Deuterium	No additional targets, ~¼ of objects have higher S/N requirements	No additional targets, ~¼ of objects have higher S/N requirements
Cospatial intergrations for extended objects	Yes*	No
Slit Width (arcsec)	≤ 5º (2.5 - 10 μm) ≤ 10º (10 - 36 μm)	≤ 5º (4 - 18 μm)
Slit Length (arcsec)	≥ 40º	≥ 20º
Absolute Pointing Accuracy (arcsec, 3σ)	1.6º (⅓ narrowest slit width)	1.6º (⅓ narrowest slit width)
Pointing Stability (3σ)	1º / 1000 s	1º / 1000 s
Track moving objects (rate arcsec/sec)	Yes 0.1º per second	Yes 0.1º per second

* Moderate resolution spectrograph can use slits in a "mapping mode"

6. MISSION ARCHITECTURE

The ASPIRE mission design is based on a direct flowdown of science requirements through space vehicle definition, Table 2, to ensure performance traceability and achievement of the scientific objectives. Key studies included mission lifetime (3 years versus 5 years), use of a cryostat versus a cryocooler, an Earth-trailing heliocentric orbit versus an L2 halo orbit and communications frequency with the flight segment. The design incorporates large margins and flight-proven heritage elements to reduce technical, cost and schedule risk, Table 3. The ASPIRE spacecraft has a high level of heritage from the proven *Kepler* spacecraft, while the telescope, cryostat and spectrometers draw heavily from *Spitzer* heritage. The ASPIRE Observatory has high mass and power margins and requires no technology development required

ASPIRE is compatible with all EELV launch vehicles which can provide a C_3 of +0.4 km^2/s^2. This C_3 value ensures escape into an Earth-trailing heliocentric orbit similar to *Spitzer* and *Kepler*. After three years, the spacecraft trails the Earth by ~0.35 AU. Unlike typical interplanetary missions, ASPIRE has daily launch window opportunities. A heliocentric, Earth-trailing, drift-away orbit simplifies the ASPIRE Observatory design and allows a highly efficient observing campaign with straightforward mission operations. ASPIRE can observe within a 60° wide annulus orthogonal to the sun-line, with the entire sky observable over any given 6-month period, Figure 8. During science operations, ASPIRE nominally generates ~1.7 Gbits/day of science data stored in a solid state recorder. Downlink capability corresponds to the equivalent of ~7 Gbits/day of science data. The data are sent to the ground via Ka-band link to the DSN over two 8-hour contacts per week.

***Table 2** – ASPIRE Mission Design Summary – Implementation is driven by flowdown from science requirements.*

Parameter	Value
Telescope Size and Type	1-meter, Cassegrain
Telescope Temperature	<40 K
Spectrometers	3 spectrometers, with separate parallel slits
Spectrometer I Ranges and Slit Sizes	
Moderate Resolution	2.5 - 20 μm (7.5" x 50")
High Resolution	3.1 - 17.5 μm (7.5" x 20")
Long Wavelength	20 - 36 μm (15" x 50")
Thermal Control	Passive, Sunshade
Cryogenic Method and Temp	Superfluid He; <4 K
Orbit	Stable thermal environment with no orbit keeping maneuvers
Science Mission Duration	3 years (w/2-year extension)
Science Data Volume	7 Gbits/day
Spacecraft Data Storage	64 Gbits
Telecommunications	Ka and X-band
Data Downlink Rate	2.4 Mbps (Ka-band)
Downlink Duration	4 hours (twice weekly)
Sky Accessability	Any point in the sky during year
Attitude Control Type	3-axis, zero net momentum
Attitude Determination	Star Tracker, HRG IRU
Pointing Accuracy	1 arcsec (3σ)
Pointing Stability	0.1 arcsec / 1000 sec (3σ)
Launch Date	January 1, 2016 (earliest)
Launch Date Flexibility	Any day of the year
Launch Window	Daily
Orbit type	Heliocentric Drift Away
Launch Mass	2167 kg
Launch energy	$C_3 = +0.4\ km^2/s^2$
Baseline mission duration	3 year, w/2 year extension option
Launch Site	Eastern Test Range, KSC
Launch Vehicle	EELV (Atlas V 401)

***Table 3** – ASPIRE has high heritage and large margins to minimize risk.*

Parameter	Heritage/Margin
Telescope Heritage	*Spitzer, HiRISE*
Telescope Design	All aluminum
Spectrometer Heritage	*MIPS, IRS*
Spectrometer Design	All aluminum, common design for all arms
Spectrometer Arms and Resolutions	
Moderate Resolution Spectrometer	2.5 - 5 μm; λ/Δλ = 3,000
	5 - 10 μm; λ/Δλ = 3,000
	10 - 20 μm; λ/Δλ = 2,500
High Resolution Spectrometer	3.1 - 5 μm; λ/Δλ = 25,000
	6 - 10 μm; λ/Δλ = 25,000
	11 - 17.5 μm; λ/Δλ = 25,000
Long Wavelength Spectrometer	20 - 36 μm; λ/Δλ = 900
Focal Plane Type and Temps	
2.5 - 5 μm wavelength range	InSb (<20 K)
5 - 20 μm wavelength range	Si:As (<7 K)
20 - 36 μm wavelength range	Si:Sb (4 K)
Cryostat Heritage	*Spitzer*
Cryogen Volume and Temp	650 l (1.5 K)
Cryogen Lifetime	4.5 years (Incl margin)
Orbit Type	Heliocentric Drift Away
Orbit Heritage	*Spitzer, Kepler*
Spacecraft Heritage	*Kepler*
Mass Contingency	427 kg (25%)
Mass Margin	488 kg (23%)
Power Contingency	84 W (18%)
Power Margin (EOL)	159 W (30%)

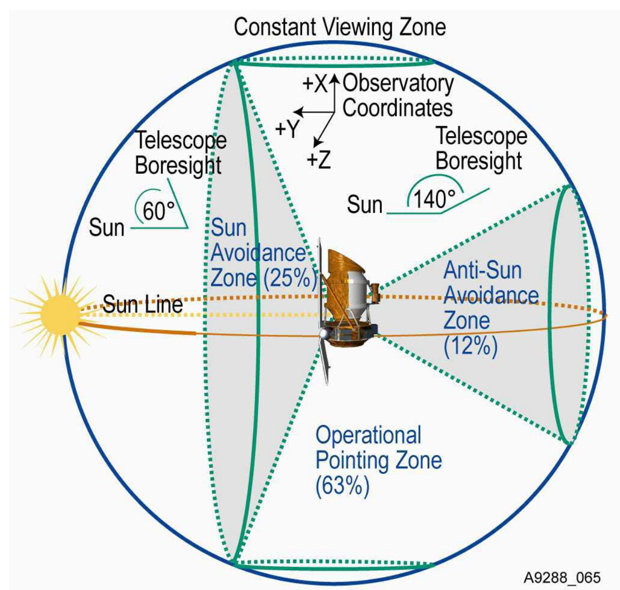


***Figure 8 –** The ASPIRE Observatory has a instantaneous viewing annulus at any given time which sweeps across the entire sky every 6 months*

The implementation concept is mature and represents a low-risk approach to meeting the scientific objectives using existing or available technologies and making use of extensive high heritage systems and common design elements in the instruments. The Observatory flight configuration is shown in Figure 9 in its stowed and deployed configurations.

7. Payload Implementation

ASPIRE achieves its scientific goals with flight proven payload technology - a superfluid helium cryostat, a one-meter diameter all-aluminum telescope, three spectrometers, focal plane assemblies (FPAs) utilizing existing detector technologies, and electronics and software from successful projects.

Payload Overview

The ASPIRE optical and mechanical designs draw on heritage from NASA-ARC and Ball cryogenic infrared instrument and telescope projects such as IRAS, IRSR, NICMOS, CTA, and the *Spitzer* IRS and MIPS instruments. A cutaway drawing of the ASPIRE payload is given in Figure 10, showing the telescope, dewar, spectrometer layout and the superfluid He tank.

The telescope feeds the three separate spectrometer instruments through parallel field slit masks. The instruments are housed within a dewar and cooled using the same approach demonstrated on *Spitzer*. All elements of the payload are based on flight-proven hardware and designs to minimize cost and risk.

Opto-Mechanical Concept

ASPIRE uses an all-aluminum, athermal design for the telescopes and instruments. The design expands on the IRS and MIPS instruments and offers "bolt and go" assembly, room temperature instrument alignment, and low cost, diamond-turned optics. Focus capability is included at the telescope secondary mirror, with focus being set at the conclusion of ground testing at the projected on-orbit focus position and then fine-tuned during telescope commissioning.

Telescope—ASPIRE uses an F/10, 100 cm diameter classical Cassegrain telescope, with diamond-turned aluminum mirrors and grain-aligned metering for operational stability. This system can be assembled and accurately aligned at room temperature prior to cold verification. The telescope uses passive thermal control, is shielded from the sun by the sunshield, with radiative cooling on the anti-sun side bringing the temperature to <40K. A rigid interface plate between the telescope and the instrument packages provides a stable structural reference for the telescope and instruments.

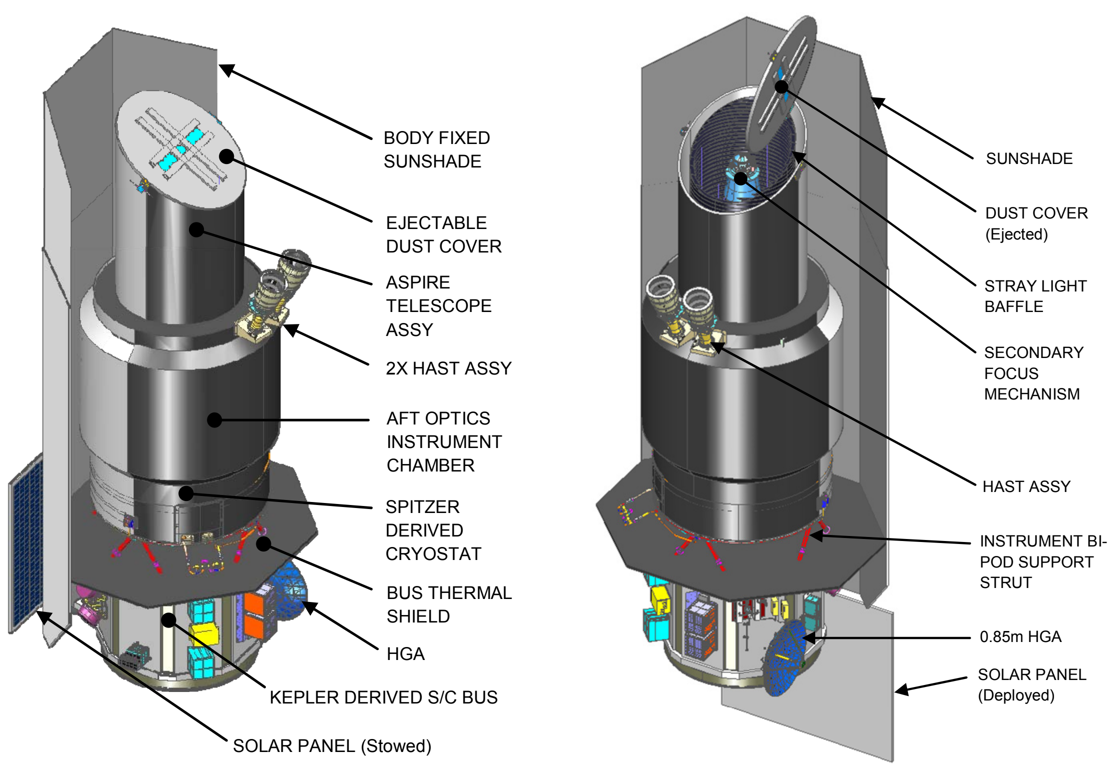


Figure 9 *– The ASPIRE Observatory shown stowed (left) and deployed (right).*

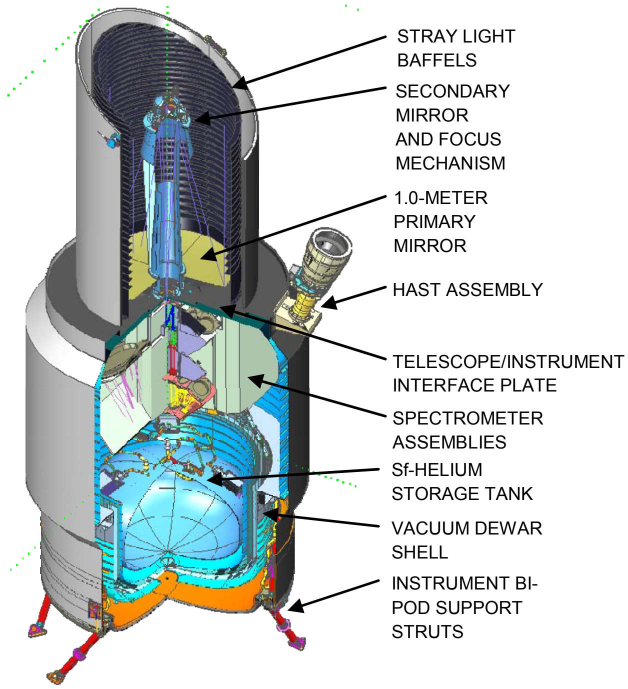


Figure 10 *– The ASPIRE Science Payload and major instrument elements.*

Instruments

ASPIRE includes three instruments with a total of 7 spectrometer arms, as summarized in Table 4. These are contained within the cryostat and maintained at 25K. Parallel slits feed the three instruments, with one slit feeding each spectrometer. All the spectrometer arms are based on a common optical design consisting of a collimating mirror followed by an echelle grating, a cross-disperser grating, and a 3-mirror camera (Figure 11). Each spectrometer is assembled within an aluminum bench/housing for "bolt and go" integration. The camera optics are designed to give 3 pixel sampling across the entrance slit for all spectrometers, supporting high spatial and spectral sampling. Channel separation between the arms is accomplished using beamsplitters after the telescope image plane slits. Nearly full spectral coverage is achieved in the moderate resolution instrument with beamsplitters with sharp transitions demonstrated in the NASA-funded ABE-ASTID beamsplitter development program (see Figure 12).

Table 4 *– The ASPIRE spectrometer performance summary*

Spectro-meter	Slit Size (arcsec)	Wavelength Range	Arms	Resolution	FPA Type	FPA Temp.
Moderate Resolution	7.5 x 50	2.5 - 20 µm	2.5 - 5 µm	3,000	InSb	<20K
			5 - 10 µm	3,000	Si:As	<7K
			10 - 20 µm	2,500	Si:As	<7K
High Resolution	7.5 x 20	3.1 - 17.5 µm	3.1 - 5 µm	25,000	InSb	<20K
			6 - 10 µm	25,000	Si:As	<7K
			11 - 17.5 µm	20,000	Si:As	<7K
Long Wavelength	15 x 50	20 - 36 µm	20 - 36 µm	900	Si:Sb	4K

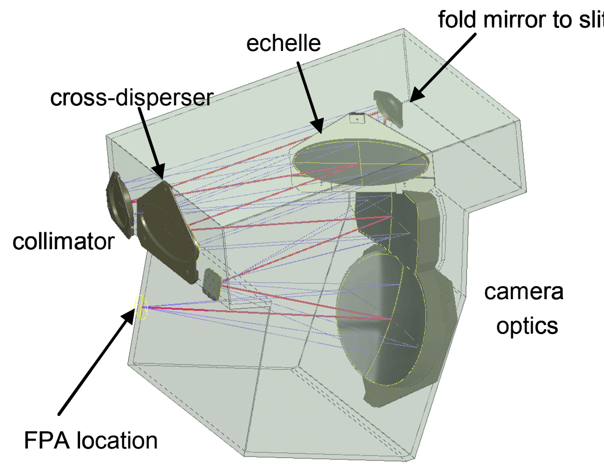


Figure 11 *– The ASPIRE Spectrometer configuration, which is replicated for each of the spectrometer arms*

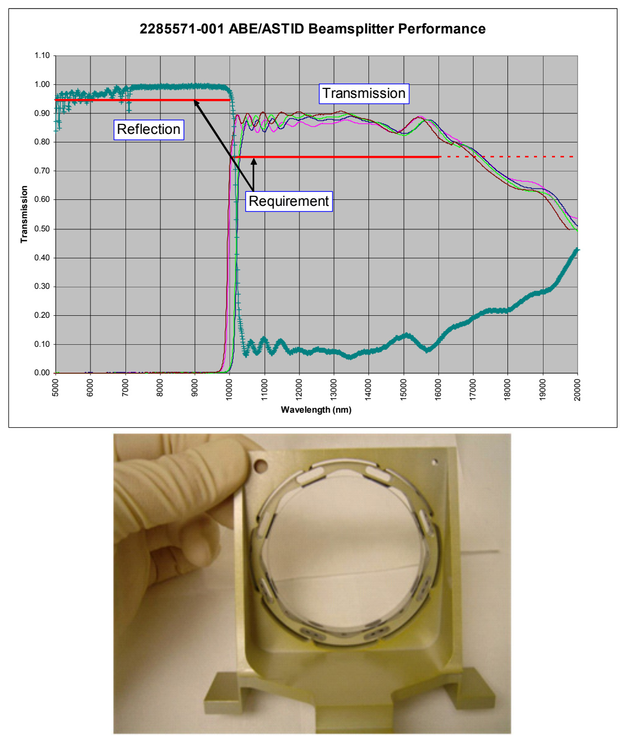


Figure 12 *– ABE-ASTID beamsplitter development (bottom) demonstrates required channel separation for ASPIRE moderate resolution spectrometer (top).*

Focal Plane Assemblies—ASPIRE uses three types of focal plane arrays, summarized in Table 5. The 2k x 2k InSb devices are traceable to 1k x 1k Alladin and Orion Chip designs that have done extensive ground-based work and 2k x 2k arrays on SB-304's that were tested and competed for flight on NIRCAM. The 256 x 256 Si:Sb device is traceable to the 128 x 128 device flown on *Spitzer*/IRS. The 1k x 1k Si:As devices are the same as the JWST MIRI detectors, see Figure 13. [49] The NASA/Ames detector group will conduct detailed screening and testing of candidate flight arrays to select sensor chip assemblies for installation into flight FPAs, with the remaining available for flight spares and engineering units.

Table 5 *– The ASPIRE FPA requirements are completely consistent with existing detectors – no new detector technology or performance improvements are required.*

Parameter	Detector Type		
	InSb	Si:As	Si:Sb
Format (pix x pix)	2048 x 2048	1024 x 1024	256 x 256
Pitch (microns)	25	25	50
Spectral band (microns)	2.5 - 5.0	5.0 - 20	20 - 36
Operating Temperature (K)	20	7	4
Read Noise (e-)	<5	<35	<35
Dark Current (e-/sec)	0.05	1	10
DQE (%)	85	70	30

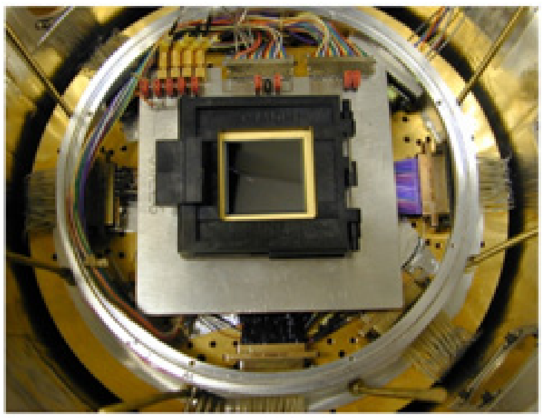


Figure 13 *– First high perfromance low temperature 1024 x 1024 Si:As IBC SCA under test at NASA Ames Research Center.*

Cryostat—The ASPIRE FPAs and optical bench will be cooled by a superfluid helium cryostat that draws directly on the *Spitzer* cryostat heritage. Like *Spitzer*, the heliocentric orbit and observational approach allows the payload to be passively cooled to <40K. The Si:Sb FPA and two of the Si:As FPAs are cooled directly by the 1.5K He tank through a conductive link, and are held at 4.0K. The remaining Si:As FPAs are cooled to 5.7K by the helium boil off gas. The two In:Sb FPAs, the optical bench, instrument housing and the cryostat vapor cooled shield are thermally linked together and cooled by the boil off gas from the 5.7K stage. This stage operates at 18.2K. The total heat leak (FPA dissipation and parasitic) into the helium tank is estimated to be 13.8 mW. A helium tank volume of 650 liters provides an estimated He II life of 4.5 years, supporting the 3.0 year mission with 50% margin.

Electronics—The ASPIRE payload electronics consist of ambient temperature electronics that drive and readout the FPAs and housekeeping devices, and a central processor unit (CPU) for controlling the payload, processing the FPA data, and interfacing to the spacecraft C&DH computer. All FPAs will be operated continuously, with only data from the active instrument being routed to the CPU for processing and recording. Only 3 unique driver/readout board designs are needed to support the ASPIRE instrument suite. The electronics consists of 12 boards (8 unique designs) mounted to a common motherboard and physically located within the spacecraft.

Software—The baseline FPA data acquisition scheme is a Foster "sample up the ramp" fit calculation for science operations, with digitization of individual reads for check-out operations, and support for sub-array/rapid reset for bright objects.

Pointing Control

ASPIRE uses Ball's High Accuracy Star Trackers (HAST), coupled through the spacecraft attitude control system, to maintain accurate pointing stability during observations. These are mounted on the telescope/instrument interface plate external to the dewar assembly, with two near-boresight wide-angle views to space to control the absolute pointing and the telescope roll during science data acquisition.

Assembly, Integration, & Test

ASPIRE's subsystems are assembled and tested separately and then integrated into the complete payload. The payload has its own controller separate from the spacecraft controller, which allows for separate payload and spacecraft fabrication, assembly, integration and test flows, and saves cost and schedule.

The ASPIRE assembly, integration, and test flow is similar to that used on *Kepler* and on the *Spitzer* instruments. Requirements-to-verification plan tracking, design and analysis document linkage, and verification test documentation linkage is tracked and controlled. Subassemblies are built and tested separately and then integrated to complete the payload. Test-as-you-fly approaches will be used to the maximum extent practical, along with a hierarchical requirements verification, as was successfully demonstrated in the *Kepler* verification program.

8. SPACECRAFT BUS

The ASPIRE spacecraft design takes advantage of flight proven technology in a heliocentric driftaway orbit, incorporating high heritage from the recent *Kepler* spacecraft, and has large margins in all spacecraft performance parameters. This reduces development and mission risk and the associated cost risk. Over 70% of the hardware is flight-proven and flight-qualified. The remaining systems are based on flight qualified designs, modified for the ASPIRE application. Key characteristics are summarized in Table 6.

Configuration and Arrangement

The Observatory flight configuration is shown in Figure 9 in stowed and deployed configurations. Subsystem components mount to the outer faces of the bus's shear panels, Figure 14. The avionics architecture is the same as used for *Kepler*, which minimizes mass and power consumption by centralizing all command, control, and data handling functions in redundant flight processors. The ASPIRE Observatory mass properties are summarized in Table 7 and show a 23% margin in mass at separation, on top of 25% allocated mass contingency.

***Table 6** – The ASPIRE spacecraft characteristics are strongly based on Kepler capabilities and heritage.*

Parameter	Characteristics
Solar Array Type, Size	Single rigid panel, 4.0 m^2
Array Power	911-W (EOM)
Solar Cell Type	Triple Junction (28% efficiency)
Battery Type, Capacity	Li-ion, 20 A-hr
Data Storage	64 Gbits
Max Record, Playback Rate	7 Mbps, 4.8 Mbps
Telecommunications	X-band up/down 25-W
	Ka-band down 30-W
Data Rates Up, Down	2.0 kbps, 2.4 Mbps
Attitude Determination	Star Tracker, FGS, HRG IRU
Attitude Control	3-axis Z.N.M. RCS desaturation
Pointing Accuracy	1 arcsec (3-sigma)
Pointing Stability	0.1 arcsec/1000 s (3-sigma)
Propulsion/RCS	Cold-gas nitrogen, fully redundant
Deployables	Solar array - 1-time (1-axis)
	Dust cover - 1-time ejection

Spacecraft Subsystem Summary

Structure and Mechanisms—The ASPIRE spacecraft hexagonal primary structure is all aluminum, similar to *Kepler*. The solar array substrate and sunshield are constructed of honeycomb material using aluminum core and graphite-epoxy facesheets. The single-panel solar array is deployed by a flight-proven, paraffin-based hinge set and restraint mechanism and mounted on a single-axis gimbal.

Electrical Power—The ASPIRE spacecraft uses the *Kepler* spacecraft direct energy transfer electrical power system designed for simplicity and reliability. Table 8 summarizes the Observatory power budget and includes contingencies and margins. The design features 100% flight-proven hardware. Power generation is provided by a single wing, single axis-deployed 4.0-m^2 array sized to provide power balance for all mission modes. The array uses currently available triple-junction solar cells with 28.5% efficiency to provide a minimum of 698 W EOL. Energy storage is provided by a 20 A-hr Li-ion battery capable of supporting 3 hours of S/C operation after separation from the LV and before the array is sun-pointed. Battery charging is controlled by solar array switching.

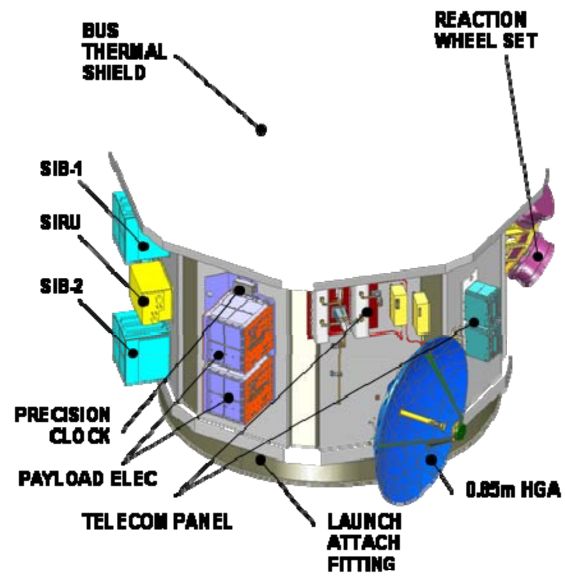


***Figure 14** – ASPIRE spacecraft bus layout with externally-mounted components.*

***Table 7** – The ASPIRE Observatory mass breakout has ample margin for even the lowest performance heritage EELV launch vehicle.*

Item	CBE (kg)	Cont. (%)	Mature (kg)
Spacecraft Bus (Total, wet)	611	19%	725
Science Payload (Total, wet)	1129	28%	1442
ASPIRE Observatory (Total, wet)	1740	25%	2167
Atlas 501* Capability to C3=0.4	2655		2655
Margin on S/C Mass at Separation	915		488
Margin on S/C Mass at Separation (%)	53%		23%

*NOTE: * - Lowest performance heritage EELV*

Command, Control and Data Handling—ASPIRE's modular and block redundant CC&DH approach maximizes the use of flight proven and flight-qualified components and minimizes cost and development risk by using standard interfaces (MIL-STD-1553B and RS422) for subsystem and payload elements. It is implemented by circuit cards in the redundant *Kepler*-heritage ASPIRE Control Boxes (ACB) and Subsystem Interface Boxes (SIB) along with an internally-redundant Bus Control Assembly (BCA). The ACBs and SIBs provide sufficient computational capability, including margin, and selectable science downlink telemetry rates from 64 bps to 2.4 Mbps. The program memory and high throughput capabilities of the processor minimize CC&DH and FSW risk.

***Table 8** – The ASPIRE Observatory End-of-Life power margin is 30% for the worst-case orientation.*

Item	CBE (W)	Cont. (%)	Oper. (W)
Spacecraft Bus (Total)	263	10%	289
Science Payload (Total)	192	30%	250
ASPIRE Observatory (Total)	455	18%	539
Array Power, EOL (Worst-Case)			698
EOL Observatory Power Margin			159
EOL Observatory Power Margin (%)			30%

Flight Software—The core S/W package currently in use on *EPOXI* (*Deep Impact*) and *Kepler* can perform all the functions needed for ASPIRE operations, including attitude determination and control, command processing, telemetry processing, EPS and power distribution management, and CPU management. Changes to the core package will be limited to the program database modifications required to support ASPIRE's operational modes, data rates, and pointing accuracy and stability requirements.

ADCS—ASPIRE's attitude determination and control subsystem (ADCS) design is driven by requirements for 1 arcsecond pointing accuracy and 0.1 arcsecond/1000s stability. The hardware is 100% flight proven. The pointing task is simplified by the low disturbance torques encountered in heliocentric orbit. Attitude determination uses a robust stellar/inertial reference design with redundant star trackers as the primary pointing attitude and stability reference. Coarse sun sensors and a hemispherical resonator gyro-based IRU augment the tracker/sensor. This is a lower resolution but similar to that used on *Kepler*.

A 4 wheel, 3-axis, zero net momentum control system using flight-proven reaction wheels is used for attitude control. Periodic RCS thruster firings provide wheel desaturation. The solar array deploys below the bus and acts to balance the area of the sunshade to minimize solar radiation pressure torques on the spacecraft. The single-axis gimbal enables the array panel angle to be optimized for c.p.-c.m. balance and power generation during observations. All control computations are provided by the SCA processor.

Communications—ASPIRE uses a *Kepler*-heritage, dual X-band/Ka-band telecom approach including SDSTs. The spacecraft is body pointed for the twice-weekly science data downlinks using its body-fixed HGA. All telecom components represent 100% flight proven hardware. Risk is further reduced by large link margins. ASPIRE communications use the DSN 34-m BWG subnet. Science data are downlinked at Ka-band through the HGA. The data rate at maximum Earth range is 2.4 Mbps, with higher downlink rates available at closer Earth ranges.

Cold-Gas RCS—The ASPIRE RCS has a straightforward block redundant design with 100% flight-proven components. Twelve 1.5 N, nitrogen cold-gas reaction control system (RCS) thrusters, split between the block redundant sides, are grouped in 4 clusters on the bottom of the bus's lower deck to maximize their moment arms and minimize pressurant consumption. Thruster locations and orientations minimize the possibility of contamination to the payload. The subsystem is single failure tolerant and is configured as two separate, independent systems. ASPIRE's four pressurant tanks provide 100% reserve on the design pressurant loading. The selected cold gas system implementation has been reviewed extensively on both the *StarLight* and *Kepler* programs.

Thermal Control System—The ASPIRE TCS maintains all S/C and payload equipment within flight-required temperature ranges for all mission phases and spacecraft attitudes. Thermal control is simplified by ASPIRE's operational approach, which keeps equipment compartment radiator surfaces largely normal to the sunline. This allows the use of standard MLI blankets, OSRs, second surface films, and heaters to cope with the incident solar flux.

9. ASPIRE MISSION OPERATIONS

After launch into an Earth driftaway orbit, there is a two-month on-orbit checkout. This allows sufficient time for the telescope to cool, the system to equilibrate, and instruments to be calibrated. A calculation of the nominal ASPIRE object list indicates the full science mission can be accomplished in under 3 years. The only consumables of the mission are the superfluid helium and the cold gas system for momentum management. The 650 liters of superfluid helium is estimated to support a cold operations lifetime of 4.5 years, and the cold gas system is sized for a 5-year mission. Science data downlinks occur nominally twice a week during science operations.

10. CONCLUSIONS

The Astrobiology Space Infrared Explorer (ASPIRE) is a Probe-class mission concept developed as part of NASA's Astrophysics Strategic Mission Concept studies to address the questions (1) "Where do we come from?" and (2) "Are we alone?" as outlined in NASA's Origins Program. ASPIRE uses infrared spectroscopy to explore the identity, abundance, and distribution of molecules of astrobiological importance throughout the Universe. ASPIRE's observational program is focused on investigating the evolution of ice and organics in all phases of the lifecycle of carbon in the universe, from stellar birth through stellar death and exogenous delivery of these compounds to planetary systems while also addressing the role of silicates and gas-phase materials in interstellar organic chemistry. Specifically, ASPIRE searches for spectral signatures from organics including: alkanes, alkenes, aromatics, ethers, alcohols, aldehydes, ketones, and nitriles, and trace, key gas phase species such as H_2O, OH, and H_2.The target lists are chosen to observe statistically significant samples of objects of varied types to achieve the science objectives.

ASPIRE achieves these goals using a highly sensitive, cryogenically-cooled telescope in an Earth drift-away heliocentric orbit, armed with a suite of infrared spectrometers to detect, identify, and determine the abundance of molecular species, particularly organics, throughout the universe. The ASPIRE observatory uses a cooled, 1-m-class telescope optimized to efficiently obtain high quality infrared spectra in the 2.5-36 micron wavelength region. This is done by obtaining spectra for a comprehensive range of solar system, galactic, and extra-galactic environments and the interfaces between them. ASPIRE is designed to obtain continuous moderate resolution spectra from 2.5-36 microns at spectral resolutions of about 2500 (2.5-20 microns) and 900 (20-36 microns). ASPIRE also obtains high resolution spectra (resolutions of 25,000) over selected windows in the 3.1-18 micron region. The ASPIRE suite of instruments provides the ability to study both gas-phase and solid-state materials in space. The ASPIRE mission design includes significant cryogen and propellant margins to support an extended observing campaign.

This paper summarized the results of the ASPIRE Origins Probe Mission Concept Study while focusing on its high heritage mission implementation. The ASPIRE spacecraft has a high level of heritage from the proven *Kepler* spacecraft, while the telescope, cryostat and spectrometers draw heavily from *Spitzer*. Key characteristics of the ASPIRE mission include: EELV launch, Earth-trailing, heliocentric driftaway orbit, *Kepler*-derived spacecraft, *Spitzer*-derived superfluid-Helium cryostat, 1-meter-diameter all-aluminum telescope, three spectrometer instruments with common design features, existing-technology focal plane arrays, high mass (26% contingency with 23% margin for smallest EELV) and power (18% contingency with 30% margin) margins, 3-yr mission lifetime (with 2-year extension), and no technology development required.

REFERENCES

[1] Allamandola, L. J., Hudgins, D. M., & Sandford, S. A. (1999). Modeling the Unidentified Infrared Emission with Combinations of Polycyclic Aromatic Hydrocarbons. *Astrophys. J. (Letters)* **511**, L115-L119.

[2] Pendleton, Y. J., & Allamandola, L. J. (2002). The organic refractory material in the diffuse interstellar medium: Mid-infrared spectroscopic constraints. *Astrophys. J. Suppl. Ser.* **138**, 75-98.

[3] Turner, B. E. (2001). Deuterated molecules in translucent and dark clouds. *Astrophys. J. Supplement Series* **136**, 579-629.; van Dishoeck, E. F., Blake, G. A., Draine, B. T., & Lunine, J. I. (1993). The Chemical Evolution of Protostellar and Protoplanetary Matter. In *Protostars and Planets III*, eds. E. H. Levy & J. I. Lunine, (Univ. of Arizona Press: Tucson), pp. 163-241.

[4] Sandford, S. A. (1996). The Inventory of Interstellar Materials Available for the Formation of the Solar System. *Meteoritics and Planetary Science* **31**, 449-476.

[5] cf. Bernstein, M. P., Dworkin, J. P., Sandford, S. A., Cooper, G. W., & Allamandola, L. J. (2002). The Formation of Racemic Amino Acids by Ultraviolet Photolysis of Interstellar Ice Analogs. *Nature* **416**, 401-403.

[6] Cruikshank, D. P., & Khare, B. N. (2000). Planetary surfaces of low albedo: Organic material throughout the Solar System. In *A new Era of Bioastronomy*, ASP Conf. Ser, Vol. 213, (G. Lemarchand & K. Meech, eds.), pp. 253-261.

[7] cf. Roussel, H., Sauvage, M., Vigroux, L., & Bosma, A. (2001). The relationship between star formation rates and mid-infrared emission in galactic disks. *Astron. Astrophys.* **372**, 427.

[8] cf. (a) Swain, M., Bouwman, J., Akeson, R., Lawler, S., & Beichman, C. (2008). The mid-infrared spectrum of the transiting exoplanet HD 209458b. *Astrophys. J.* **674**, 482-497.; (b) Swain, M. R., Vasisht, G., & Tinetti, G. (2008). The presence of methane in the atmosphere of an extrasolar planet. *Nature* **452**, 329-331.

[9] W. Borucki and Summers, “Photometric method of detecting other planetary systems,” ICARUS, Vol. 58, 1984, pp.121.

[10] D. G. Koch, W. J. Borucki, K. Cullers, E. W. Dunham, L. Webster, T. Miers, and H. J. Reitsema, “System Design of a mission to detect Earth-sized planets in the inner orbits of solar-like stars,” JGR-Planets, Vol. 101, No. E4, 1996, pp. 9297-9302.

[11] D. G. Koch, W. J. Borucki, L. D. Webster, E. W. Dunham, J. M. Jenkins, J. Marriott, and H. J. Reitsema, "Kepler: A space mission to detect Earth-class exoplanets," SPIE Conference 3356, Space Telescopes and Instruments V, March 1998, pp. 599-607.

[12] Borucki, W. J., Caldwell, D., Koch, D. G., Webster, L. D., Jenkins, J. M., Ninkov, Z., and Showen, R., "The Vulcan Photometer: A Dedicated Photometer For Extrasolar Planet Searches," PASP, 113, 2001, pp. 439-451.

[13] R. Duren, D. Koch, W. Borucki, J. Jenkins, D. Mayer, E. Bachtell, P. Batuk, D. Peters, and A. Harvey, "Validation & verifcation of the Kepler planet-detection mission," 2003 IEEE Aerospace Conference, Big Sky, Montana, USA, 8-15 March 2003.

[14] D. Koch, W. Borucki, D. Mayer, D. Caldwell, J. Jenkins, E. Dunham, J. Geary, E. Bachtell, W. Deininger, R. Philbrick, D. Shafer. C. Stewart, R. Duren, and N. Gautier, "The Kepler Mission: A search for terrestrial planets – development status," IAC-03-Q.1.01, 54th International Astronautical Congress, Bremen, Germany, October 2003.

[15] D. Koch, W. Borucki, E. Dunham, J. Geary, R. Gilliland, J. Jenkins, D. Latham, E. Bachtell, D. Berry, W. Deininger, R. Duren, T. N. Gautier, L. Gillis, D. Mayer, C. Miller, D. Shafer. C. Sobeck, C. Stewart, and M. Weiss, "Overview and Status of the Kepler Mission," Optical, Infrared, and Millimeter Space Telescopes, SPIE Conference 5487, Glasgow, Scotland, June 2004.

[16] W. D. Deininger, D. D. Miller, and A. C. Harvey, "Kepler Mission Spacecraft Concept Description," Paper 11.07, 204th American Astronomical Society Meeting, Denver, CO, USA, June 2004.

[17] K. Gwin, "Attitude Determination and Control for the Kepler Spacecraft," AAS 02-058, 25th Annual AAS Guidance and Control Conference, Breckenridge, Colorado, USA, Feb 6-10, 2002.

[18] M. W. Werner, T. L. Roellig, F. J. Low, G. H. Rieke, M. Rieke, W. F. Hoffmann, E. Young, J. R. Houck, B. Brandl, G. G. Fazio, J. L. Hora, R. D. Gehrz, G. Helou, B. T. Soifer, J. Stauffer, J. Keene, P. Eisenhardt, D. Gallagher, T. N. Gautier, W. Irace, C. R. Lawrence, L. Simmons, J. E. Van Cleve, M. Jura, E. L. Wright, and D. P. Cruikshank, "The SPITZER Space Telescope Mission," The Astrophysical Journal Supplement Series, 154:1–9, The American Astronomical Society, Sept. 2004.

[19] J. R. Houck, T. L. Roellig, J. van Cleve, W. J. Forrest, T. Herter, C. R. Lawrence, K. Matthews, H. J. Reitsema, B. T. Soifer, D. M. Watson, D. Weedman, M. Huisjen, J. Troeltzsch, D. J. Barry, J. Bernard-Salas, C. E. Blacken, B. R. Brandl, V. Charmandaris, D. Devost, G. E. Gull, P. Hall, C. P. Henderson, S. J. U. Higdon, B. E. Pirger, J. Schoenwald, G. C. Sloan, K. I. Uchida, P. N. Appleton, L. Armus, M. J. Burgdorf, S. B. Fajardo-Acosta, C. J. Grillmair, J. G. Ingalls, P. W. Morris, and H. I. Teplitz, "The Infrared Spectrograph (IRS) On The SPITZER Space Telescope," The Astrophysical Journal Supplement Series, 154:18–24, The American Astronomical Society, Sept. 2004.

[20] cf. Volk, K., Xiong, G.-Z., & Kwok, S. (2000). Infrared Space Observatory spectroscopy of extreme carbon stars. *Astrophys. J.* **530**, 408-417.

[21] Sandford, S. A., Pendleton, Y. J., & Allamandola, L. J. (1995). The Galactic Distribution of Aliphatic Hydrocarbons in the Diffuse Interstellar Medium. *Astrophys. J.* **440,** 697-705.

[22] Hony, S., Van Kerckhoven, C., Peeters, E., Telens, A. G. G. M., Hudgins, D. M., & Allamandola, L. J. (2001). The CH out-of-plane bending modes of PAH molecules in astrophysical environments. *Astron. Astrophys.* **370**, 1030-1043.

[23] Onaka, T., Yamamura, I., Tanabe, T., Roellig, T. L., & Yuen, L. (1996). Detection of the mid-infrared unidentified bands in the diffuse galactic emission by IRTS. *Publ. Astron. Soc. Japan* **48**, L59-L63.

[24] Sandford, S. A., & Allamandola, L. J. (1993). Condensation and Vaporization Studies of CH_3OH and NH_3 Ices: Major Implications for Astrochemistry. *Astrophys. J.* **417**, 815-825.

[25] cf. Boogert, A. C. A., Pontoppidan, K. M., Lahuis, F., Jørgensen, J. K., Augereau, J.-C., Blake, G. A., Brooke, T. Y., Brown, J., Dullemond, C. P., Evans, N. J., II, Geers, V., Hogerheijde, M. R., Kessler-Silacci, J., Knez, C., Morris, P., Noriega-Crespo, A., Schöier, F. L., van Dishoeck, E. F., Allen, L. E., Harvey, P. M., Koerner, D. W., Mundy, L. G., Myers, P. C., Padgett, D. L., Sargent, A. I., Stapelfeldt, & Karl R. (2004). Spitzer Space Telescope Spectroscopy of Ices toward Low-Mass Embedded Protostars. *Astrophys. J. Suppl. Ser.* **154**, 359-362.

[26] Dworkin, J. P., Deamer, D. W., Sandford, S. A., & Allamandola, L. J. (2001). Self-Assembling Amphiphilic Molecules: Synthesis in Simulated Interstellar/Precometary Ices. *Proc. Nat. Acad. Sci. USA* **98**, 815-819.

[27] cf. Cronin, J. R., & Chang, S. (1993). Organic matter in meteorites: Molecular and isotopic analyses of the Murchison meteorite. In *The Chemistry of Life's Origins*, eds. J. M. Greenberg, C. X. Mendoza-Gomez, & V. Pirronello, (Kluwer Academic Publishers: Netherlands), pp. 209-258.

[28] Sandford, S. A., Aléon, J., Alexander, C. M. O'D., Araki, T., Bajt, S., Baratta, G. A., Borg, J., Bradley, J. P., Brownlee, D. E., Brucato, J. R., Burchell, M. J., Busemann, H., Butterworth, A., Clemett, S. J., Cody, G., Colangeli, L., Cooper, G., d'Hendecourt, L., Djouadi, Z., Dworkin, J. P., Ferrini, G., Fleckenstein, H., Flynn, G. J., Franchi, I. A., Fries, M., Gilles, M. K., Glavin, D. P., Gounelle, M., Grossemy, F., Jacobsen, C., Keller, L. P., Kilcoyne, A. L. D., Leitner, J., Matrajt, G., Meibom, A., Mennella, V., Mostefaoui, S., Nittler, L. R., Palumbo, M. E., Papanastassiou, D. A., Robert, F., Rotundi, A., Snead, C. J., Spencer, M. K., Stadermann, F. J., Steele, A., Stephan, T., Tsou, P., Tyliszczak, T., Westphal, A. J., Wirick, S., Wopenka, B., Yabuta, H., Zare, R. N., & Zolensky, M. E. (2006). Organics Captured from Comet 81P/Wild 2 by the Stardust Spacecraft. *Science* **314**, 1720-1724.

[29] cf. Knutson, H. A., Charbonneau, D., Allen, L. E., Fortney, J. J., Agol, E., Cowan, N. B., Showman, A. P., Cooper, C. S., & Megeath, S. T. (2007). A map of the day-night contrast of the extrasolar planet HD 189733b. *Nature* **447**, 183-186.

[30] Cowan, N. B., Agol, E., & Charbonneau, D. (2007). Hot nights on extrasolar planets: mid-infrared phase variations of hot Jupiters. *MNRAS* **379**, 641-646.

[31] cf. Tran, Q. D., Lutz, D., & Genzel, R. *et al.* (2001). ISOCAM-CVF 5 - 12 micron spectroscopy of ultraluminous infrared galaxies. *Astrophys. J.* **552**, 527-543.; Spoon, H. W. W., Armus, L., Cami, J., Tielens, A. G. G. M., Chiar, J. E., Peeters, E., Keane, J. V., Charmandaris, V., Appleton, P. N., Teplitz, H. I., & Burgdorf, M. J. (2004). Fire and Ice: Spitzer Infrared Spectrograph (IRS) Mid-Infrared Spectroscopy of IRAS F00183-7111. *Astrophys. J. Suppl. Ser.* **154**, 184-187.

[32] Houck, J. R., Soifer, B. T., Weedman, D., Higdon, S. J. U., Higdon, J. L., Herter, T., Brown, M. J. I., Dey, A., Jannuzi, B. T., Le Floc'h, E., Rieke, M., Armus, L., Charmandaris, V., Brandl, B. R., & Teplitz, H. I. (2005). Spectroscopic Redshifts to z > 2 for Optically Obscured Sources Discovered with the Spitzer Space Telescope. *Astrophys. J.* **622**, L105-L108.

[33] Smith, et al., 2009, ApJ, in press.

[34] Rigby, J. R., Marcillac, D., Egami, E., Rieke, G. H., Richard, J., Kneib, J.-P., Fadda, D., Willmer, C. N. A., Borys, C., van der Werf, P. P., Pérez-González, P. G., Knudsen, K. K., & Papovich, C. (2008). Mid-Infrared Spectroscopy of Lensed Galaxies at 1 < z < 3: The Nature of Sources Near the MIPS Confusion Limit. *Astrophys. J.* **675**, 262-280.

[35] . Sandford, S. A., Bernstein, M. P., & Dworkin, J. P. (2001). Assessment of the interstellar processes leading to deuterium enrichment in meteoritic organics. *Meteoritics and Planetary Science* **36**, 1117-1133.

[36] Zinner, E. (1988). Interstellar cloud material in meteorites. In *Meteorites and the Early Solar System*, eds. J. F. Kerridge & M. S. Matthews, (Univ. Arizona Press: Tucson), pp. 956-983.

[37] Sandford et al, "Understanding the Evolution of Molecules in Space: Implications for Astrophysics, Astrochemistry, and Astrobiology". White Paper on Decadal Survey webpage at http://www7.nationalacademies.org/bpa/Astro2010_SWP_byTitle.html.

[38] http://astrochemistry.org/ASPIRE-ABE-DEX.html.

[39] Decadal Survey White Paper at: http://www.astrochemistry.org/pubs/ASPIRE_white_paper2009.pdf

[40] Cruikshank, Dale P.; Sandford, S. A.; and Roellig, T. L., "The Astrobiology Space Infrared Explorer (ASPIRE) Mission," American Astronomical Society, AAS Meeting #213, #428.01; Bulletin of the American Astronomical Society, Vol. 41, p.259.

[41] K. A. Ennico, and S. A Sandford, "Astrobiology explorer mission concepts (ABE/ASPIRE)," Elsevier Ltd., COSPAR 2007, Advances in Space Research, Vol. 40, Is. 5, pp. 649-654.

[42] Scott Sandford, "The Astrobiology Space Infrared Explorer (ASPIRE) Astrophysics Strategic Concept Mission," Presentation to the NAI Planetary System Formation Focus Group (PSFFG), January 7, 2009.

[43] Scott Sandford, "The Astrobiology Space Infrared Explorer A Medium-Class Astrophysics Mission Dedicated to Astrobiology," ASPIRE factsheet 2009, www.astrochemistry.org/factsheets/ASPIREfactsheet2009.pdf.

[44] Ennico, K. A., & Sandford, S. A., "Identifying Organic Molecules in Space: The AstroBiology Explorer (ABE) Mission Concept," Proc. SPIE 5487, #3, 1553-1562.

[45] Ennico, K.A., Sandford, S. A, et al., "The AstroBiology Explorer (ABE) MIDEX mission concept: Identifying organic molecules in space." SPIE Symposium Astronomical Telescopes and Instrumentation, Conference 4850, IR Space Telescopes and Instruments, Waikoloa, Hawaii, 22-28 August 2002. Proc. SPIE Vol 4850, pp 1149-1160.

[46] Ennico, K., Sandford, S., Cox, S., Ellis, B., Gallagher, D., Gautier, N., Greene, T., McCreight, C., Mills, G., and Purcell, W., "The AstroBiology Explorer (ABE) MIDEX Mission Concept," Instruments, Methods, and Missions for Astrobiology IV," eds. R. B. Hoover, G. V. Levin, R. R. Paepe, & A. Y. Rozanov, Proc. SPIE 4495, 273-282.

[47] Sandford, S., Allamandola, L., Bregman, J., Ennico, K., Greene, T., Hudgins, D., Strecker, D. (2002). Identifying Organic Molecules in Space – The AstroBiology Explorer (ABE) MIDEX Mission Concept. In "Instruments, Methods, and Missions for Astrobiology IV," eds. R. B. Hoover, G. V. Levin, R. R. Paepe, & A. Y. Rozanov, Proc. SPIE 4495, 170-181.

[48] Sandford, S., Greene, T. P., Allamandola, L., Arno, R., Bregman, J., Cox, S., Davis, P., Gonzales, A., Hanel, R., Hines, M. Hudgins, D., Jackson, R., Kittel, P. Maa, S., & McCreight, C., "The AstroBiology Explorer (ABE) MIDEX Mission," SPIE Conference on UV, Optical, and IR Space Telescopes and Instrumentation (Conf. 4013), 26-31 March 2000, Munich, Germany. Proc. SPIE Vol 4013, pp 604-615.

[49] K. Ennico, M. McKelvey, C. McCreight, R. McMurray Jr., R. Johnson, A. Hoffman, P. Love, N. Lum "Large Format Si:As IBC Array Performance for NGST and Future IR Space Telescope Applications", IR Space Telescopes and Instruments. Edited by John C. Mather. Proceedings of the SPIE 4850, pp. 890-901 (2003).

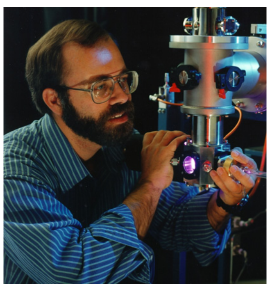
BIOGRAPHY

William Deininger *is a staff consultant in mission systems engineering at Ball Aerospace & Technologies Corp with 29 years of industry experience. Dr. Deininger currently supports new business including NASA AOs (New Frontiers, Discovery, MIDEX and SMEX), and focused mission RFPs such as Micromissions, ST3, LightSAR, ST5, TPF, and Constellation X. He has also supported various defense new business and proposal efforts. He was the functional manager for the Mission Systems Engineering group at Ball for 2 years and prior to that, the Kepler Flight Segment Manager. Prior to his role on Kepler, he was the Chief Systems Engineer on the Mars Micromissions Project and then the StarLight Project. Prior to joining Ball Aerospace, Dr. Deininger worked at FiatAvio-BPD in Italy for 9 years, as a Member of the Technical Staff at JPL for 8 years and as a research assistant at Argonne National Laboratory for 1½ years. He is a member of the IEEE and an Associate Fellow of the AIAA. He received his Ph.D. in Aerospace Engineering from the Università degli Studi di Pisa in Italy, his M.S. in Plasma Physics from Colorado State University, and his B.S. in Physics from the State University of New York.*

William Purcell *is a senior advanced systems manager at Ball Aerospace & Technologies Corp. with 26 years of science, space mission and concept development experience. Dr. Purcell supports the development of new space mission concepts, focusing on understanding the scientific objectives of the mission and coordinating with scientists and engineers to ensure the mission will meet its scientific objectives. He has worked in this capacity at BATC for 12 years. Prior to working at BATC, Dr. Purcell was a Research Professor in the Physics and Astronomy Department at Northwestern University working on NASA's Compton Gamma Ray Observatory. He received an MBA from the Kellogg Graduate School of Management at Northwestern University, a Ph.D. in Astrophysics from Northwestern University, and a B.S. in Physics and Mathematics from Elmhurst College.*

Paul Atcheson *is a staff consultant in payload systems engineering at Ball Aerospace & Technologies Corp and has 30 years of experience in remote sensing and optical system development. Dr. Atcheson's specific areas of expertise include lens design, optical system design and development, electro-optical phenomenology and electromagnetic theory, laser communications, passive and active sensing, image processing, and wavefront sensing and control. Experience covers over 50 projects (including Kepler, JWST, and the HST COSTAR) and studies, working in all phases of a product's development cycle, from the IR&D proof-of-concept and proposal stages through the final product integration and qualification. Programmatic involvement includes development of initial concept ideas and product designs, taking over troubled projects, and supporting and leading both routine and emergency technical activities. He received both his Ph.D. and M.S in optical sciences from the University of Arizona and his B.S.E.E from Union College.*

Gary Mills *is a principal engineer at Ball Aerospace and Technologies Corp. with 26 years of experience in the design, analysis, fabrication, and test of aerospace thermal, cryogenic and optical systems. He has authored or co-authored over 30 publications in his field. including a chapter in the Space Thermal Control Handbook and a chapter in a book on optical refrigeration. Mr. Mills managed the design, manufacture and test of a thermoelectric cooler (TEC) subsystem on a solid nitrogen dewar for the Near Infrared Camera Multi-Object Spectrometer (NICMOS) instrument currently installed in the Hubble Space Telescope. Mills was the Program Manager of the NASA-funded Optical Cryocooler Development program which demonstrated the world's first optical refrigerator. He received his B.S. and M.S. in aerospace engineering from the University of Colorado.*



Scott Sandford *is a member of Astrophysics Branch at NASA's Ames Research Center, where he has worked for the past 23 years, and is a co-leader of Ames' Astrochemistry and Astrophysics Laboratory. Dr. Sandford received BS degrees in Mathematics and Physics from the New Mexico Institute of Mining and Technology in 1978 and an MA and PhD in Physics from Washington University in St. Louis in 1981 and 1985, respectively. He has over 25 years of experience in the fields of meteoritics, is an editor of the journal Meteoritics and Planetary Science, and has helped find many meteorites in Antarctica. Dr. Sandford also does extensive work in the areas of laboratory astrophysics, astrochemistry, and astrobiology, and participates in infrared astronomy studies using ground-based, airborne, and spaceborne observatories. He has used the combined techniques of infrared astronomy and laboratory astrophysics to identify a number of new molecular species in space, many of interest to exobiology. Current laboratory interests include the study of the physical, chemical, and spectroscopic properties of polycyclic aromatic hydrocarbons (PAHs) and astrophysical ice analogs relevant to interstellar, cometary, and planetary environments. Dr. Sandford is the Principal Investigator on a number of space infrared observatory mission concepts, including the one described in this paper, and one comet sample return mission concept. He was also a Co-Investigator on the successful Stardust Discovery Mission and is currently working on the joint Japanese-US Hayabusa Mission.*

Robert Hanel *is a Systems Engineer at NASA Ames Research Center currently working in the Small Spacecraft Office. Robert has 20 years of experience working instruments, spacecraft systems, and mission designs for NASA scientific mission including work on SIRTF and SOFIA. Robert has a M.S. and a B.S in Electrical Engineering from California Polytechnic State University in San Luis Obispo.*

Mark McKelvey *is a Research Engineer at NASA Ames Research Center currently working in the Instrument Technology Branch. Mark has 29 years of experience working instruments, detectors, and low temperature electronics. Mark has a M.S. in Material Science from Stanford and a B.A. in Physics from the University of California at Santa Cruz.*

Robert McMurray *is a Solid State Physicist at NASA Ames Research Center currently working in the Instrument Technology Branch. Robert has 30 years of experience working development of infrared detection and photo-conductors. Robert has a Ph.D. in Physics from University of California at Berkeley and B.S degrees in Physics, Chemistry, & Mathematics from Tulane University.*