Development of the Wide-field Infrared Survey Explorer (WISE) Mission

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ABSTRACT

WISE is a NASA MIDEX mission to survey the entire sky in four bands from 3 to 25 microns with sensitivity about 500 times greater than the IRAS survey. WISE will find the most luminous galaxies in the universe, find the closest stars to the Sun, and detect most of the main belt asteroids larger than 3 km. WISE launch is scheduled in November, 2009 on a Delta 7320-10 to a 525 km Sun-synchronous polar orbit.

This paper gives an overview of WISE including development status and management approach. WISE flight system design is single string with selected redundancy and graceful degradation. Wherever possible, design heritage from prior missions is pursued and properly reviewed to reduce development time and cost. Further risk reduction is achieved since the WISE spacecraft has no deployable mechanisms and no propulsion. Nonetheless, a complex space mission with a sophisticated cryogenic IR telescope such as WISE demands a partnership of multiple organizations in government research, academia, and industry. With a cost cap and relatively short development schedule, it is essential for all WISE partners to work seamlessly together. This is accomplished by a single management team representing all key partners and disciplines in science, systems engineering, mission assurance, project and contract management. WISE uses a variety of management tools including frequent team interaction, schedule, milestone and critical path analysis, risk analysis, reliability analysis, earned value analysis, configuration management, and management of schedule and budget reserves. After a successful mission critical design review in June, 2007, WISE has completed building most of the flight hardware, and started integration and test within payload and spacecraft.

Keywords: Infrared, cryogenic, ultraluminous galaxies, asteroids

1. INTRODUCTION

The Infrared Astronomical Satellite (IRAS) mission launched in 1983 gave us what is still our best all-sky survey in mid−infrared. Vast advancement of IR detector technology over two decades makes it possible to dramatically improve the IRAS results. The Wide-field Infrared Survey Explorer (WISE) mission will use a 40cm telescope to perform an all-sky survey, covering at least 95% of the sky, at 4 infrared wavelengths: 3.3, 4.7, 12 and 23μm (bands 1, 2, 3, and 4). These bands will achieve sensitivity limits of 120, 160, 650, and 2600 μJy, respectively.

The WISE mission concept was originally proposed in 1998 as MIRASS (Mid-IR All-Sky Survey). It was re-proposed as a NASA MIDEX (Medium Explorer) mission in 2001 with the name NGSS (Next Generation Sky Survey) which was changed to WISE in late 2002. Phase A project formulation started in 2002. Funding constraints in 2004 and 2005, however, slowed the formulation and preliminary design activities. The project was authorized and fully funded for detailed design and development in 2006. WISE is a mission component of the long running and successful Explorers Program managed by NASA Goddard Space Flight Center (GSFC).

Modeling, Systems Engineering, and Project Management for Astronomy III, edited by George Z. Angeli, Martin J. Cullum, Proc. of SPIE Vol. 7017, 70170M, (2008) · 0277-786X/08/$18 · doi: 10.1117/12.790087

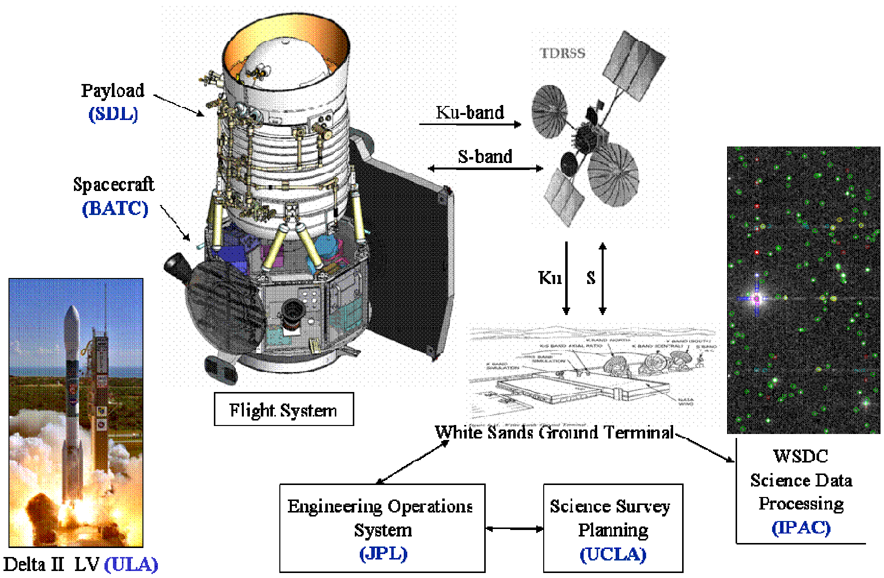

Figure 1 WISE Mission Elements and Operation Concept

The WISE mission is led by the Principal Investigator (PI) from the University of California, Los Angeles (UCLA) who leads the WISE science team which currently consists of more than twenty scientists representing over ten scientific organizations. The team contains members with experience from many previous and on-going infrared instruments from both flight and ground missions. The PI also oversees the education and public outreach program which is carried out by the University of California, Berkeley.

While the PI has overall responsibility for project resources and mission success, he has delegated authority to implement the project to JPL. Figure 1 shows the WISE mission elements, operation concept, and responsible organizations. The Jet Propulsion Laboratory (JPL) leads overall project management, mission and systems engineering, mission assurance, spacecraft and payload procurement, launch site operation; Ball Aerospace and Technology Corporation (BATC) provides the spacecraft, leads flight system integration and test, and supports launch operations; Utah State University's Space Dynamics Laboratory (SDL) provides the payload; the Mission Operation System (MOS) team is at JPL with support from UCLA, BATC, SDL, and Caltech's Infrared Processing and Analysis Center (IPAC) which is responsible for data analysis, archive and distribution.

Since the successful completion of mission critical design review (CDR) in June, 2007, WISE has completed critical design in all elements and subsystems. With few exceptions, the payload and spacecraft have each completed subsystem hardware development and are well into integration and test.

The WISE flight system will be launched by a Delta 7320-10 rocket in Nov., 2009 to a 525km Sun-synchronous polar orbit with 6am ascending node. Commands and telemetry are via TDRSS S-band, science data and stored engineering data are down-linked via TDRSS Ku band at 100Mbps. The primary mission will last for 7 months including one month of in-orbit checkout and six months of survey to meet all science requirements. Authorization for six-month mission extension has been requested; the cryogen is expected to last for thirteen months.

2. Science

We live in an era when the basic reconnaissance of the universe is underway. Sensitive all-sky surveys across the electromagnetic spectrum are imminent or have recently been completed, but the mid-infrared (IR) lags behind. The four WISE bands represent about 500 times better sensitivity than IRAS at 12 and 23µm, and 500,000 times better sensitivity than the Cosmic Background Explorer (COBE) at 3.3 and 4.7µm. Past surveys with such a leap in sensitivity and covering much or all of the sky have revealed dramatic surprises, which have significantly changed our knowledge of our universe and have created entire new areas of astronomical investigation. Examples include galaxy clusters from the Palomar Observatory Sky Survey (POSS), quasars from the 3C radio survey, planetary debris disks from IRAS, and L and T-dwarf stars from 2MASS. WISE will deliver to the scientific community an all-sky catalog with over one million calibrated rectified images covering the whole sky, and catalogs of half a billion objects, in these four bands. WISE wavelength range will fill the wavelength gap between the 2MASS all-sky survey at 1.2 – 2.2 μm and the Akari (formerly Astro-F) all-sky survey at 50 and 100 μm, and largely overlaps that planned for JWST. The legacy of the WISE survey will endure for decades as it has for IRAS.

WISE is optimized to achieve its two primary science goals, which are to

- Study the nature and evolutionary history of ultra-luminous IR galaxies, and identify the most luminous galaxies in the universe; map clusters of galaxies and large scale structure within 7-billion light-years; and
- Measure the space density, mass function, and formation history of brown dwarf stars in the solar neighborhood identifying the closest stars to the sun.

In addition, WISE will address other fundamental topics in astrophysics, including

- Determining the radiometric albedos for almost all known asteroids, including Main Belt and Near Earth Objects (>>100,000);
- Measuring the very faint end of the luminosity function of protostars in nearby star formation regions
- Contributing to the understanding of the evolution of circumstellar disks

More detailed WISE science and science requirements are discussed in a previous SPIE paper (Mainzer et al, 2005).

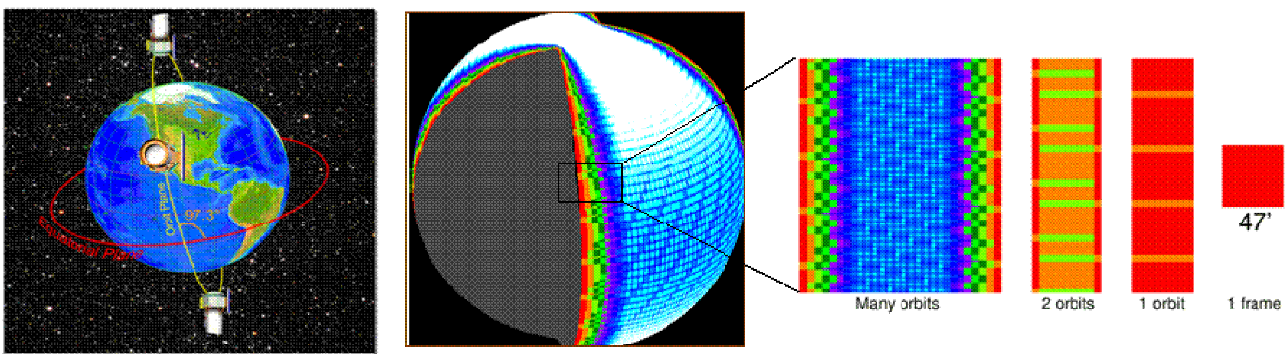

Figure 2 Survey Approach

3. WISE Mission Description and Implementation

Key mission features to achieve the science objectives level-one requirements are:

- A slowly precessing (~1°/day) Sun-synchronous terminator orbit which allows repeated sampling of a sky segment on several adjacent orbits, enabling detection of stationary sources and moving objects. This orbit provides a complete all-sky survey in 6 months.
- A 40cm telescope with a scan mirror that compensates for orbital motion during exposures, enabling step-and-stare sampling of the sky.
- A two-stage, solid hydrogen cryostat to cool the telescope and detectors for the 7-month primary mission. The extra 6-month cryostat lifetime margin will assure accomplishment of the primary mission and provide for the potential for a 6-month extended mission.
- A three axis stabilized spacecraft with a TDRSS-compatible, Ku-band downlink telecom system.

Figure 2 shows the WISE survey approach which achieves its all sky coverage by scanning a circle nearly perpendicular to the Earth-Sun line. The spacecraft will maintain a constant pitch rate while a scan mirror in the payload "freezes" the sky during each 8.8s exposure. Each frame has a 47 x 47 arcmin field of view (FOV) with 10% overlap between frames but 90% overlap between orbits. A more detailed description of WISE mission planning in various seasons has been discussed in an award-winning AIAA student paper (Kanner, 2007).

3.1. System Design and Development Philosophy

The WISE system design philosophy is guided by the fact that it is a cost-capped MIDEX mission with a unique solid-hydrogen cooled cryogenic payload, a relatively short development and test cycle, short mission duration, and a non-critical launch which can occur any day of the year. The WISE system design is generally single string; limited redundancy and graceful degradation are implemented after careful trade studies including technical performance, reliability enhancement, complexity and cost. Starting from the conceptual design, WISE possessed ample margins beyond normal guidelines in all key technical resources such as mass, power, cryogen, processing throughput and memory, etc. As a result the WISE system design has been remarkably stable. Electronics parts and reliability analysis are tailored to the relatively short mission in low-Earth orbit. To further enhance reliability, WISE strives to minimize the usage of electro-mechanical mechanisms. Examples include a fixed, body-pointing high-gain antenna instead of a gimbaled mechanism, a fixed solar array instead of a deployable one, no propulsion, and flash memory data storage rather than the original baseline of RAID (redundant array of independent hard disks). Extra care was taken on the only moving parts within the flight system: reaction wheels assemblies (RWA, 4ea.) for attitude control, and the cryogenic scan mirror essential for efficient science survey. The fourth RWA was added during preliminary design to provide functional redundancy; and the scan mirror was prototyped and tested early. Wherever possible, heritage design and components are utilized to reduce development cost and risk. In a variety of cases, heritage design from recent or on-going missions have paid off significantly for WISE by minimizing non-recurring engineering and trouble shooting cost.

The system design is modular with relatively simple interfaces between different development organizations. Figure 1 shows the WISE flight system including the payload element and the spacecraft element. The payload consists of the instrument and the three electronic boxes. The instrument is the main part of the payload connected to the spacecraft via four sets of bi-pods for structural support and thermal isolation. Electrical cables of low thermal conductance connect the instrument to three payload electronic boxes which reside inside the spacecraft bus. The simple interfaces allow the development and testing of the payload and of the spacecraft to proceed in parallel until each element is fully tested.

The WISE test program is designed to accommodate the unique nature of the solid-hydrogen payload without violating JPL’s test-like-you-fly philosophy. SDL and their cryostat partner Lockheed Martin Advanced Technology Center (LMATC) built and operated the only two previous flight solid-hydrogen cryostats, SPIRIT-III and WIRE. Since environmental testing involving a solid-hydrogen-filled cryostat requires extensive and expensive safety measures in the test facility, WISE built a high-fidelity payload thermal, mass, and dynamic simulator (TMDS) and use the TMDS in lieu of the flight payload during the flight system structure and dynamic test, and thermal vacuum test. This approach allows maximum time for the flight payload to be thoroughly tested and qualified prior to its final integration with the flight spacecraft. Subsequent system test can be limited to only the essential tests such as electromagnetic interference/compatibility test and acoustic test.

Another unique aspect of the WISE design philosophy is an outgrowth of using a fixed mounted high gain antenna (HGA) on a cryogenic mission. WISE must avoid pointing the optical aperture at the Sun and the Earth. This means that the flight system maneuvers for downlink must maintain attitudes that allow communication through the HGA while simultaneously keeping the optical aperture away from the Sun and Earth. Development of a robust Sun and Earth avoidance design has involved all areas of the WISE system and operations elements.

3.2. Spacecraft

The WISE spacecraft is based on the BATC single-string RS300 bus and software package, which traces it heritage to the 2005 Deep Impact mission’s Impactor spacecraft and the 2007 Orbital Express mission’s Nextsat spacecraft. Several modifications to the RS300 baseline have been necessary to accommodate the WISE mission: the size of the bus structure is increased to structurally match the size of the instrument; the fixed mounted Ku-band HGA and Ku transmitter are added to the telecom system; a flash memory card (FMC) with 96GB capacity is developed for WISE to store science and engineering data prior to downlink; propulsion is deleted; flight software is enhanced with extra fault protection features to prevent the telescope bore-sight from exposure to the Sun or the Earth.

The WISE spacecraft subsystems include:

- Mechanical and structures
- Electrical power and distribution subsystem (EPDS)
- Command and data handling (C&DH)
- Telecom (TCOM)
- Attitude determination and control subsystem (ADCS)
- Thermal control subsystem (TCS)
- Flight software (FSW)
- Fault protection (FP)

The subsystems work together as a nearly autonomous system to support four spacecraft modes: wait (launch) mode, safe mode, emergency mode, and operate mode which includes normal science survey, downlink and standby. Figure 3 shows key spacecraft components.

Since Phase A, WISE has performed extensive analyses to ensure that the heritage three-axis stabilized ADCS architecture indeed meets all pointing and stability requirements with adequate margins. A set of coarse sun sensors (CSS) determine the Sun vector in any spacecraft orientation. Two redundant star tracker assemblies (STA) provide primary measurements for high accuracy, three-axis, on-board attitude and rate determination. The STAs were flight spares from NASA's WMAP mission and were refurbished by BATC to include the latest star catalog and WISE-compatible electrical interfaces. As inherited hardware items, the STAs were subsequently re-tested to ensure all WISE requirements are met. During launch and emergency mode when the STAs are powered off, ADCS achieves coarse determination of 3-axis attitude using the magnetic field vector synthesized from the magnetometer measurement and the sun vector from the CSS, while the rate information is derived from an inertial measurement unit (IMU). Attitude control is provided by a set of four reaction wheel assemblies (RWA). The fourth wheel was added around PDR for redundancy since any three out of four functioning RWA would be sufficient for the spacecraft to achieve accurate pointing and steady slewing. The magnetometer and three torque rods with redundant windings are used for wheel momentum management; momentum dumping by the torque rods occurs during science data downlinks or above 45° latitude where extensive overlap exists in sky coverage. No on-board propulsion is needed to achieve all WISE requirements. After separation from the launch vehicle, the spacecraft (thus WISE flight system) is always under the ADCS control. During science survey, the payload takes images continuously every 11 sec while the spacecraft maintains a continuous pitch rate that matches the orbit pitch. All ADCS hardware items have been delivered to BATC.

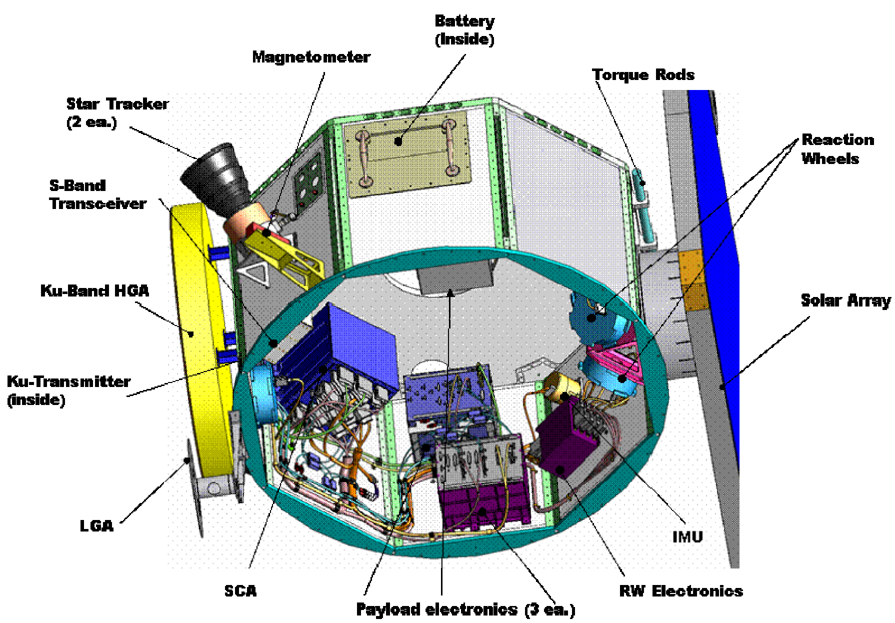

Figure 3 Spacecraft Components

The C&DH subsystem resides in the spacecraft control avionics (SCA) box. Developed by Southwest Research Institute (SwRI) for BATC, the SCA hosts a cPCI bus and a VME bus. The cPCI bus provides a platform for a single board computer (SBC) where the FSW resides, a non-volatile memory board (NVM), the flash memory card (FMC), command and telemetry interface board (CTB), 1553B interface, and a mission unique board (MUB). The VME bus provides a platform for power control and distribution boards, ADCS and thermal control interface boards, as well as a network interface board (NIC) which hosts the emergency mode controller (EMC). The EMC is a separate processor which takes over the spacecraft control in the event of an emergency when the FSW is out of service or if a severe low voltage occurs. The EMC will maintain bare minimum functions, enough to maintain spacecraft safety, allowing the ground control time to resolve problems and command it back to FSW control. During science data collection, the MUB board, among other functions, receives science data from the payload, performs lossless Rice 2.1:1 compression and stores it in the FMC; during downlink, the MUB retrieves data from the FMC and sends it the Ku-transmitter. With 96 GB of data storage, the FMC can accommodate more than 3 days of compressed science and engineering data. The WISE FMC is an example of leveraging the rapid technology advancement in semiconductor industry for space application, providing reliable and scalable mass data storage with reduced mass, cost and power consumption. The SCA is scheduled for delivery to WISE in June, 2008.

Of all the spacecraft subsystems, the TCOM subsystem has the most new design from the RS300 baseline. It is designed to communicate with the TDRSS in S-band and Ku-band. With design heritage from the GLAST and LRO missions, the S-band transceiver supports forward and return links to TDRSS for command uplink and housekeeping telemetry downloads. Two S-band omni antennas are located at opposite sides of the spacecraft to provide more than 80% coverage for command uplink, with 100% coverage achievable with two TDRSS satellites in communication with WISE. With heritage from the GLAST mission, the Ku transmitter supports a 100Mbps single access return link for all compressed science and engineering data downlink. The Ku-band HGA traces its heritage to many commercial satellites; it uses slotted waveguide flat plate arrays to meet WISE requirements. All TCOM hardware deliveries are scheduled to complete in June, 2008.

Multiple factors including the sun-synchronous orbit, short mission duration, the relatively low power consumption and relatively large launch vehicle fairing size, allowed the WISE spacecraft to use a fixed solar array (SA). The SA uses 3.0 m^2 of 28.0% efficiency ultra-triple-junction solar cells to produce 467 W end-of-life power. The NextSat mission was one of the first to use a lithium ion battery in space. A similar battery with 29A-Hr capacity is used on WISE. Both the SA and the battery will be delivered to WISE in July of 2008.

Like on any other flight projects, FSW always carries schedule and cost risks until it is done. The WISE FSW is scheduled to complete the formal qualification test (FQT) in August, 2008. Thus far the FSW has maintained a nearly 80% re-use from the NextSat FSW. This has been largely accomplished by a highly disciplined change control process and perhaps more importantly, by inheriting key FSW engineers from the NextSat mission. Also important to WISE is inheriting the software test bench and development benches from NextSat with proper reconfiguration and re-certification.

FP is another subsystem whose design complexity and verification approach carry schedule risk and cost risk. WISE FP need takes advantage of all hardware elements to ensure that the payload telescope bore sight is not exposed to the Sun or Earth (see Rice and Lev-Tov, IEEE, 2008). The FP system is designed to detect impending attitude violations, suspend surveying and point the telescope in a safe attitude until ground controllers resolve the cause of the violation. The FP design and development represent an excellent collaboration between BATC and JPL, with support from SDL. The design was completed in Sept., 2007 followed by a in-depth peer review by a team of experts including spacecraft system, FP, FSW, ADCS and C&DH from both BATC and JPL. The system level test and verification will commence once FSW completes FQT.

3.3. Payload

Figure 4 shows payload subsystems and key components. The WISE payload consists of a cryogenic instrument and three control electronic boxes that reside inside the spacecraft bus. At the front of the instrument is a 40cm aperture afocal telescope, followed by a scan mirror at the exit pupil of the telescope, followed by an 8X magnification re-imaging camera, beam splitters and focal planes. The four focal plane arrays are at the heart of the instrument, each with 1024^2 pixels (2.75 arcsec/pixel), which covers a 47 arcmin squared instantaneous field of view. The cryogenic scan mirror offsets the orbital motion and freezes the sky on the arrays during each exposure. The operating temperatures are 30–34K for the 3.3 & 4.7µm detectors, 7.8 ± 0.5K for the 12 & 23µm detectors and 17K for the optical system. The cooling is provided by a two-stage solid hydrogen cryostat providing a minimum mission lifetime of 7 months allowing for a single full coverage of the entire sky. During science survey the instrument operates in a single mode, continuously scanning the sky as the sun-synchronous, 525 km altitude orbit precesses around the celestial sphere in 6 months (Larsen & Schick, 2005).

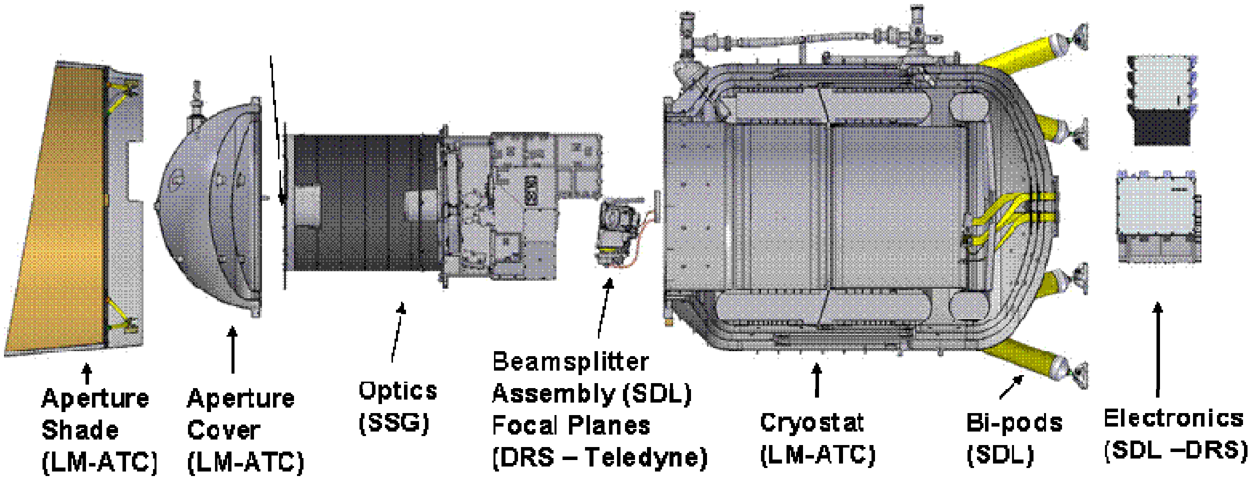

Figure 4 Payload Subsystems and Key Components

The SDL-led payload team is essentially the same collaboration and often the same people that developed the SPIRIT-III and the WIRE instruments. The cryostat is provided by LMATC, optics provided by L3-SSG, detectors and detector electronics provided by DRS (of Anaheim, CA) and Teledyne (Formerly Rockwell Scientific), and the rest by SDL. This teaming arrangement reduces development time and risk of a relatively complex instrument.

The 3.3µm and 4.7µm focal plane arrays (FPAs) will use Teledyne HAWAII 1-RG HgCdTe arrays with a 4.7µm and a 5.0µm cutoff, respectively. Although the HgCdTe arrays were initially considered “off-the-shelf” devices, a critical modification was necessary to make them compatible with the space environment. Lessons-learned from other NASA missions (JWST and Wide Field Camera-3 for Hubble) indicated that the CdTe substrate on which the HgCdTe layer is grown must be removed in order to eliminate photoluminescence in presence of proton bombardment (Johnson et al. 2004, McKelvey et al. 2004, Hill et al. 2005). The 12µm and 23µm channels will use DRS Si:As BIB detectors on a new multiplexer designed for low read noise below 10 K. In early Phase A, WISE recognized that the multiplexer carried new development risks, and funded DRS to fabricate and test the multiplexer to retire the risk early. The multiplexer met WISE requirements (Mainzer et al., 2005). DRS also provides the FPA mounts and FPA electronics.

By early 2008, all four flight detectors and detector spares had been delivered to SDL for I&T. Prior to that the detectors and detector electronics caused significant cost and schedule impacts to the WISE project. Contributing factors included the extra substrate removal process, relatively long development cycle and relatively low yield.

Fortunately, from the very beginning, the WISE project recognized the intrinsic risks associated with any detector development, and funded the detector development ahead of other payload subsystem development, which was further well ahead of the spacecraft and MOS development. Thus far this strategy has worked very well for WISE.

The WISE optical system consists of the afocal five-mirror telescope assembly with a 40 cm primary mirror, a cryogenic scan mirror to stabilize the image against the orbital rotation, followed by imaging optics and beamsplitters (Schwalm et al. 2005). The instantaneous field of view (FOV) is 47 x 47 arcmin. The afocal design allows for more compact packaging and minimal distortion across the FOV. The imager will have all reflective elements to minimize reliance on exotic materials. The four focal planes share the same FOV, with three dichroic beamsplitters separating the light first into two beams, then splitting the beams further into the four beams to illuminate the four FPAs in bands centered on 3.3, 4.7, 12, and 23μm. This optical layout allows the afocal and the imager to be assembled and tested independently, allowing good clearance for the scan mirror mechanism. All four focal planes are located near the back of the cryostat, allowing for convenient mechanical and electrical access. A system model including point spread function, wavefront error, spacecraft jitter, etc. was created to form a performance metric for image quality; current predictions show that the optical system will exceed its image quality requirements in all four bands. A separate stray light performance analysis demonstrates meeting key stray light requirement. As of June, 2008, both the afocal telescope and the imaging optics have been delivered to SDL, integrated with the flight detectors and the flight cryostat, and successfully undergone the first end-to-end test.

Two development risks in the optics were identified early on: the scan mirror as the only moving part in the instrument and the 1st beamsplitter due to its material (InSb), relatively large size (3.20 x 2.36 x 0.375 inches) and high accuracy surface requirements. A scan mirror mechanism prototype was developed and underwent performance, cryogenic, and vibration testing. A beamsplitter prototype was also successfully fabricated, polished, and tested against vibration and cryogenic environmental requirements.

The cryogenic support system consists of a solid hydrogen cryostat, a deployable cover, an aperture shade and thermally isolating support structure to the spacecraft (Naes et al. 2005). The dual-stage, solid hydrogen cryostat is designed for a 7-month mission, with another 6 months margin. The primary tank will operate at ~6.5K and will cool the 12 and 23μm focal planes to 7.8K±0.5K. The secondary tank operates at <12K and acts as a guard to the primary tank to intercept essentially all parasitic heat loads from the ambient structure. The secondary tank also provides instrument cooling of the telescope and scan mirror to <17K and acts as the heat sink for the 32K, band 1 and 2 HgCdTe focal planes. Two vapor-cooled shields, mounted intermediately along the support structure, use the hydrogen effluent vapor to absorb a significant portion of the incoming parasitic heat. A deployable dome-shaped aperture door assembly closes out the vacuum space. In a mission critical event during IOC the aperture door is spring-ejected following the release of three pyro-actuated separation nuts. The design has fully independent pyro arm and fire mechanisms. An aperture shade is mounted at the telescope entrance to insulate the open cryostat system from direct Earth and Sun heat loads after the cover ejection. Additionally, hydrogen gas is vented out of the cryostat through opposing low thrust vent nozzles that minimize torques on the flight system. The flight cryostat was delivered to SDL in Feb., 2008 and has been successfully tested three times at cryogenic temperature.

The fully-assembled WISE instrument will be characterized on the ground using special purpose calibration facilities at SDL, followed by hydrogen testing and environmental testing. The fully qualified payload will be delivered to BATC in April 2009 for integration and test with the flight spacecraft. The final calibration will be derived from on-orbit observation of selected celestial sources during IOC.

As a surrogate for the flight payload, the TMDS was scheduled for integration with the flight spacecraft to undergo flight system level quasi-static (structure), random vibration and thermal vacuum (TVAC) tests. An anomaly occurred during the TMDS standalone quasi-static test in February, 2008. Subsequent investigation revealed the failure of a structure support inside TMDS due to deficiency in predictions of material strength. Although the TMDS is a test article, not flight hardware, it nonetheless shares the identical structural element with the flight payload. After a thorough investigation involving material property testing and launch environment modeling, the WISE project decided to implement a Softride^{TM} system to reduce the launch load experienced by the cryostat. The Softride^{TM} provides vibration isolation for the whole flight system; similar systems have been successfully implemented by CSA Engineering in more than a dozen space flights. Preliminary analysis indicates that a

Softride™ will provide ample margin to meet the WISE requirements. The Softride™ is scheduled for delivery to BATC in October, 2008, followed by integration with the spacecraft and the repaired TMDS to resume flight system level random vibration and TVAC tests. In hindsight, the TMDS and its early testing helped reveal a structure deficiency and thus saved WISE from a later (and much more costly) failure in the flight cryostat.

3.4. Mission Operations System

The WISE Mission Operations System is divided into three subsystems: science survey planning at UCLA, Engineering Operations at JPL, and WISE Science Data center (WSDC) at IPAC (See Figure 1). The PI team at UCLA provides science survey planning for the mission. It generates the spacecraft pointing and scan parameters to execute an optimized survey plan allowing for SAA (South Atlantic Anomaly) compensation, lunar avoidance and if necessary recovery of gaps resulting from inadvertent data losses, e.g. after a safe mode recovery. This leads to a nominal survey plan providing coverage of better than 99% of the sky with more than 8 independent exposures during the 6 months survey mission.

Engineering operations for the mission are provided by the JPL Earth Science Mission Center, which is currently operating the Jason spacecraft. The Engineering Operations Subsystem (EOS) team of JPL engineers and operators is supported by engineers from BATC and SDL during on-orbit operations. The EOS is responsible for the health and safety of all WISE mission operations. It will monitor the flight system and perform all necessary spacecraft and payload maintenance operations. It provides the detailed scheduling and navigation functions and generates twice-a-week sequence loads to WISE via TDRSS.

At the beginning of each TDRSS communication pass the EOS real-time operator will establish the heath and safety status of the WISE flight system by checking the status pages for any red or yellow alarm violations or unexpected flight system configuration. In addition to this health and safety check, the housekeeping telemetry accumulated during each period of autonomy will undergo analysis by the EOS spacecraft team to identify any possible transient anomalies or unexpected flight system behavior. The EOS also provides the first step in the processing of the high rate science data when it is received via TDRSS. It will frame sync, RF decode and extract telemetry packets out of the high rate data stream, followed by packet level data accountability, which will be automatically evaluated based on pre-set thresholds for required data re-transmissions. Subsequently it will transfer the packet data via data lines to the WSDC for further processing.

The WSDC located at the Infrared Processing and Analysis Center (IPAC) is responsible for converting the raw image data from the spacecraft into final image atlas and source catalog, and to archive and distribute those products. The WSDC produces the end products from WISE to the astronomical community in the form of a photometrically and astrometrically calibrated digital image atlas covering the entire sky in the four survey bands, and a Catalog containing accurate positions and brightness for all sources extracted from the image data. WISE data processing is organized into four basic functions, each handled by a separate subsystem at the WSDC: ingest, data reduction pipelines, final product generation, and archiving.

WISE data products will be made accessible to the community in collaboration with the NASA Infrared Science Archive (IRSA) at IPAC. WISE data release will occur in two stages, 6 and 17 months after the end of the nominal on-orbit lifetime of 7 months. The preliminary release will include image atlas and source catalogs derived from the first 50% of the sky surveyed and will contain sources that have SNR of 20 or higher in unconfused regions of sky, which will allow immediate use of WISE data by the community. The final release will include sources to about SNR = 5 and will be accompanied by more extensive quality analysis and product validation.

The data will be maintained in a way that distribution of the complete WISE source catalogue via DVD to frequent users is possible. All image data will be made available in accordance with the flexible image transport system (FITS) astronomical data standard, and tables will be in the widely used IPAC table format. In order to ensure survivability in case of a major catastrophe causing the loss of the data at the IPAC facility a complete copy of the WISE data set and software source code will be deposited at a secure off-site location. For a more detailed description of the WISE mission operations concept, see Heinrichsen et al. (2006).

4. Project Management

The success of WISE will ultimately depend on not just excellence in science and engineering but also competence in project management. The development of the WISE mission requires close collaboration among a large number of organizations spread around the country. The teaming arrangement originated in the proposal phase leveraged the strength of each participating organization based on their recent experience and proven track record.

As a JPL managed project, WISE follows JPL's Flight Project Practices (FPP) and Design Principles (DP), which are intended to guide the management, design and development of all JPL flight projects. WISE was proposed, approved and funded with the implementation assumption of maximizing contractor's proven practice and experience. This apparent conflict is resolved by having JPL engineers understand contractor's process and procedures, identify any deviations from JPL's FPP and DP, and review the rationales. In all but a few cases the contractor's practice has been determined to be acceptable. These acceptable deviations are documented in waivers which are approved by the WISE project and JPL management. In a rare case when the contractor's practice is deemed by JPL to be unacceptable, the contractor is directed to use the JPL's approach. This process gives JPL insight into contractor's process and allows JPL to be selective in providing oversight in high risk areas. Special engineering teams are formed as needed to resolve engineering issues that require coordinated efforts cross elements. The WISE practice strongly demonstrates that the best technical oversight is achieved when JPL engineers participate as team members in engineering design and problem solving. Members on the special engineering teams are not limited to existing engineers on the project; rather the teams include experts from the JPL technical divisions and other non-JPL affiliations. A long list of examples includes: fault protection architecture, design and testing, Sun and Earth Pointing Prevention design and analysis, pyro system design and testing, MUB end-to-end testing, EMI/EMC test and risk evaluation, Si:As detector multiplexer radiation susceptibility testing, FSW test bench utilization, system fault tree analysis, contamination control requirements, TVAC planning, TMDS anomaly investigation and recovery, harness routing and implementation, EEE parts review and approval, electronics boards reliability analysis, end-to-end optical performance, mission scenario test planning, launch site operation planning, cryogenic service and GSE on launch pad, Softride feasibility study and implementation, etc.

The WISE project promotes open, broad and frequent communications among all organizations. The JPL WISE project manger (PM) chairs a monthly face-to-face (FTF) meeting with the management team which consists of the PI, all JPL office managers directly under the PM, and WISE program leaders from BATC, SDL and IPAC. This FTF meeting provides a round-table platform to exchange opinions and to thoroughly discuss important issues on the project. Perhaps more importantly it has served as a regular team building event, reminding us of our common goals, enhancing mutual understanding and removing unnecessary barriers between different organizations. The WISE PM also conducts a monthly project element status review where all mission elements report recent progress, upcoming events, schedule and milestone status, on-going issues and mitigation plans.

Managing and communicating risks are important aspects of project management. Anyone on WISE can generate a new risk input. Each risk is assessed by likelihood, impact, mitigation approach and cost. Each element maintains a compiled risk list and provides input to a project level risk list maintained by the WISE PM, who in turn reports medium and high risk items monthly to JPL and NASA. It is WISE policy to aggressively mitigate any mission risk; development risks are accepted judiciously to manage budget and schedule reserves.

JPL's flight system manager and payload manager function as contract technical managers (CTM) for BATC and SDL contracts with JPL, respectively. Each CTM conducts monthly management review (MMR) within the element, which is open to all on the project. During the MMR each subsystem reports detailed technical achievement, near term planning, milestone and earned value (EV) status including schedule and cost variances. EV is practiced by BATC, SDL and the JPL project as whole. Each CTM also hosts weekly tag-up telecons to discuss any issues of interest.

Open communication facilitates strict scope and change control. This is made possible by clearly established contractual agreements and associated roles and responsibilities. Scope and budgetary baselines are established at all levels down to individual tasks. The CTM authorizes any scope changes for that element. WISE PM and PI control project budget reserve. If additional budget resource is required, the CTM submits to the PM a lien request against the project reserve. Out of scope tasks can only be performed after the associated lien is approved. WISE PM maintains an open book on project budget reserve status and lien list, which are reviewed by the entire management team at each FTF meeting. This practice effectively promotes shared responsibility, ownership, and mutual trust.

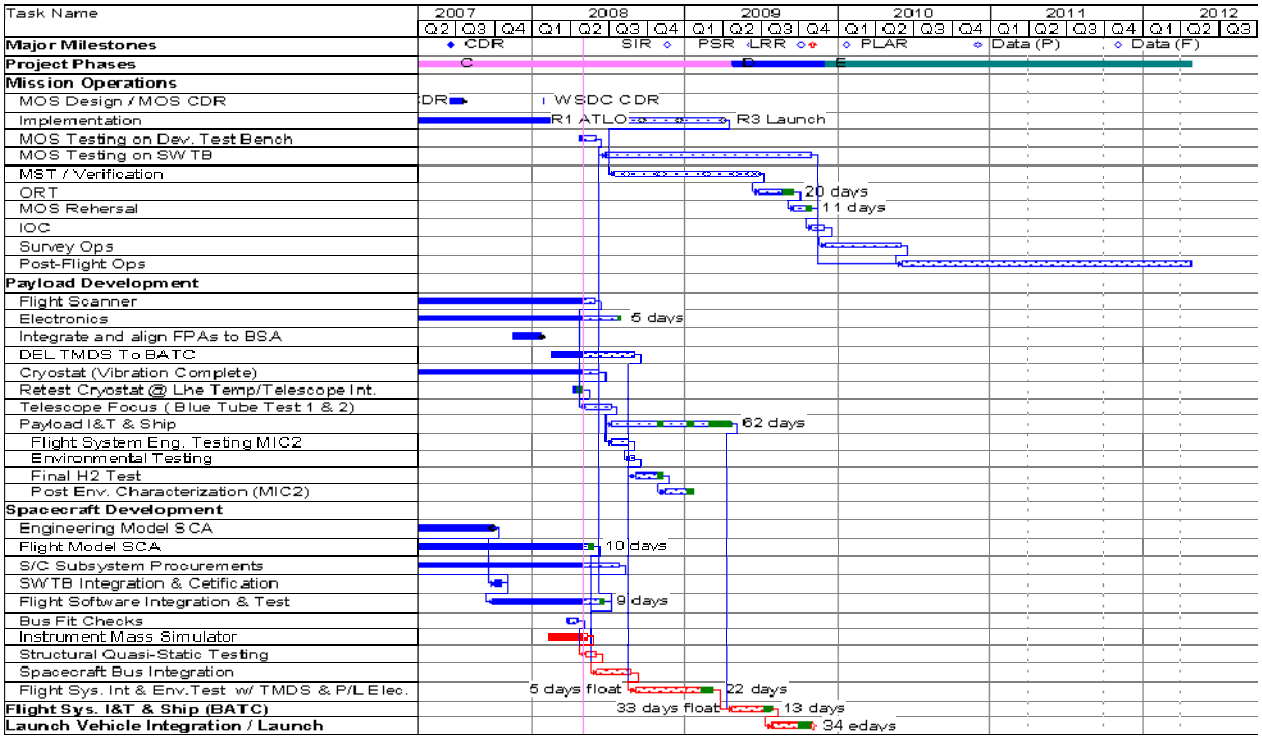

Figure 5 WISE Top Level Schedule

The same rigor in change control also applies to engineering changes. The WISE project system engineer (PSE) chairs the mission system engineering team (MSET) which consists of system engineers from all elements and key subsystems. A weekly MSET telecom led by the PSE addresses all important technical and design issues, reviews technical documents and engineering change requests (ECRs). ECRs are used for engineering changes impacting an element or the system. Each ECR clearly identifies changes, rationale, affected hardware/software and documentation, estimated schedule and cost impact, and approval signatures. The project change control board (CCB) is convened as needed to approve ECRs. An approved ECR often leads to an authorized scope change and thus a new baseline. In fact, WISE system requirements and system design have remained remarkably stable, a testament to the soundness of the PI's original concept.

Performance with respect to an integrated budget and schedule baseline is tracked using the EV system. An effective implementation of the EV is predicated on good planning and schedule with adequate schedule margins. In practice, one drawback of the EV reporting is that it tends to be 2-3 weeks late by the time an EV report is compiled. To facilitate timely schedule management, WISE uses, in parallel, a milestone reporting system. At the beginning of each fiscal year, each element submits a set of meaningful schedule milestones (the number being proportional to its budget) for the next 12 months. The PM tracks these milestones weekly to gauge the project schedule performance in near real time. This seemingly simple approach performs exceptionally well, and gets further validated each month by the EV report. Figure 5 shows the WISE top level schedule; the critical path through spacecraft I&T has 60 work days of schedule margin prior to flight system I&T in April, 2009. The schedule margin exceeds JPL's guideline for schedule reserve to effectively support the Nov. 1, 2009 launch date.

The WISE project follows JPL guidelines for conducting technical and programmatic reviews. An Independent and Integrated Review Team (IIRT) serves as the review board for all WISE project level or system level formal reviews such as PDR and CDR. The IIRT is co-chaired by non-JPL experts and the members consist of subject experts mostly from outside of JPL. Selected IIRT members participate in element and subsystem reviews to maintain continuity. Review findings and requests for action (RFAs) from formal reviews are recorded, tracked, and closed only with the concurrence from the initiators. In addition to higher level formal reviews, WISE emphasizes and seems to benefit the most from in-depth, albeit informal, peer reviews at subsystem or lower levels, and at each stage of design maturity. The WISE project strives to find the most experienced experts as reviewers, regardless of their affiliations. Whenever possible, the same reviewers are invited back for continuity. This is done in consultation with JPL technical divisions. Peer reviews are also performed on special topics such as system grounding, pyro electronics design and testing, fault protection, etc.

As flight hardware deliveries are near completion, WISE is transitioning rapidly to the I&T phase. SDL is responsible for payload element level I&T through the flight payload delivery to BATC. BATC is responsible for spacecraft element I&T as well as flight system level I&T. JPL, under the direction of the PSE, is ultimately responsible for the verification and validation of the flight system performance. JPL engineers participate in lower level test readiness reviews and witness tests as needed on a non-interfering basis. At the flight system Level I&T, both JPL and SDL engineers will be present at BATC. JPL leads operations at the launch site.

Despite the management practices employed on WISE, the successful implementation of a mission ultimately comes down to the people and their team work. It is common for a WISE team member to function in multiple support roles in addition to his/her main role; we share a culture of helping each other. This has been essential to the success of WISE as a cost capped project with limited resources.

Further information on WISE can be found at http://wise.ssl.berkeley.edu/.

5. Acknowledgements

The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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