for use during I&T.

Test readiness reviews will precede the start of all significant test phases, as noted in Figure G-12. Prior to all significant integration activities, inspections and bonding measurements are performed. Tests are performed using Kepler released procedures, certified GSE, and qualified FSW, and modified only as required.

G.5 WHIPPLE SAFETY AND MISSION ASSURANCE

Consistent with NASA Procedural Requirement NPR 7120.5C and NPG 8705.4 “Risk Classification for NASA Payloads” for a Category II, Class “B” mission, the Whipple S&MA program is a design integrity program that includes rigorous design reviews; careful control of parts, materials, and processes; and a thorough program of inspection and tests. A JPL Mission Assurance Manager (MAM) will provide management and coordination of the Whipple S&MA program. JPL, SAO, and Ball Aerospace S&MA includes assurance management, system safety, reliability, environmental requirements, electronic parts requirements, hardware and software quality assurance, contamination control, alert monitoring, and Operations Assurance. All software documentation and code implementation will be compliant with the NASA Software IV&V requirements.

Design Principles exceptions and lessons learned (accepted by JPL for Kepler) will be reviewed and approved during Phase A. Reuse of these waivers (e.g., load removal, design temperature range) is essential to the build-to-print cost philosophy being used for Whipple.

Overall Ball Aerospace safety and mission assurance plans, based upon the Kepler program, will ensure cost-effective, compliant, and consistent program implementation. Existing Kepler systems analyses will be updated to reflect the Whipple configuration and operations context. S&MA requirements flow down to team members, their subcontractors, and suppliers. All team members’ applicable processes and procedures will be reviewed and assessed for compliance and consistency by JPL S&MA.

Whipple flight system reliability assessments shall be conducted for changes from the Kepler design, including worst-case analyses; fault-tree analyses; FMEA; Probabilistic Risk Assessment; and parts stress analyses. The Whipple Parts Control Board, chaired by a JPL Parts Engineer, will assess all EEE parts and radiation effects. EEE-INST-002 Level 1 parts are baselined. Only approved materials will be used. Whipple shall have 1000 hours of operating time, with the last 350 hours error free, per the Kepler Environments Data Book (569798). Flight system reliability will be achieved through prudent selection and control of electronic parts. The Kepler baseline design used on Whipple includes robust, cost-conscious margins, and the I&T program plan assures design compliance with the Kepler Environments Data Book and Environmental Verification Matrix, modified as required for Whipple. The JPL Project Safety Manager will manage the NPG 8715.3-compliant safety program and will implement EWR 127-1 requirements for launch site and ground processing. The program will include a System Safety Plan and safety analyses as required (PHA, SHA, or O&SHA) as well as range safety submittals. The MSPSP will be prepared with partner input support. Safety will review for hazards all procedures and cover hazardous operations.

Whipple's planetary protection classification is Category 1 since, in an Earth-trailing orbit, it will not encounter any solar system bodies other than possibly the Earth or the Moon. See Appendix J.7 for more information.

G.6 LAUNCH VEHICLE & CAMPAIGN

The Delta 2925-10L is assumed for Whipple (same as Kepler), based on its injected mass capability, the Whipple team’s extensive experience with Delta integration and the exceptional reliability of the Delta II vehicle. However, the existing design envelops all environments and interface requirements for AO Category II launch vehicles. The Whipple S/C is accommodated within AO Category II available fairings and uses standard payload attach fittings (PAF) per Foldout G1, Figure G-2. Whipple will reuse the Kepler Launch Services Requirements Document, simplifying LV design and interface development efforts. We verify LV interfaces with a flight PAF fit check, as part of our standard I&T flow, prior to shipment to the launch site.

Launch Operations. After completing acceptance testing, the flight system is packed in an environmentally controlled shipping con-
tainer. Our envelope allows for inexpensive, simple transportation via air ride truck to the Astrotech processing facility near KSC.

The Li-Ion flight battery is charged prior to post-ship functional testing, and the flight PAF is installed post-functional test. We conduct a final comprehensive functional test, including transmitting stored science data to a DSN ground station, verifying total system functionality before launch. Similar to DI, we will perform a wet mass properties verification without a spin balance test.

Once Whipple is transported to the launch pad, we will perform a Launch Configuration Aliveness test. The test staff remains at the launch site to provide on-hand support to the launch vehicle provider during launch vehicle integration and to provide quick response anomaly resolution.

**Critical Event Coverage.** Coverage of S/C separation will be provided by a mobile ground-based asset positioned downrange from the launch site. Options under consideration include the Kirtland AFB mobile van used for Lunar Prospector real-time separation confirmation, or the Boeing Delta IV shipborne range asset. This will be studied in more detail in the Concept Study. Costs for this coverage are enveloped by the AO launch vehicle costs as mission-unique items.

### G.7 GROUND DATA SYSTEM

**Whipple Leverages Existing Facilities and Infrastructure to Provide a Low-Risk, Low-Cost Approach to the Ground Data System.**

The Whipple Ground Data System (GDS) benefits from significant reuse of the Chandra GDS, currently being used by SAO to operate the Chandra X-Ray Observatory. The Whipple ground segment data flow diagram (Figure G-13) shows that the architecture consists of a small number of well-defined interfaces and functions. Mission operations, including mission planning and spacecraft command and control, are conducted from the Operations

![Figure G-13. Whipple ground segment and mission data flow. The ground architecture consists of well-defined interfaces with a clean, efficient separation of functions.](image-url)

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Control Center (OCC) at SAO via a direct interface to the DSN. Science Operations, including data processing and archiving and coordinating ground-based follow-up observations, are conducted at the SAO Science Operations Center (SOC), co-located with the OCC. Spacecraft engineering support is provided to the OCC by the Ball Aerospace design team, located at the Flight Planning Center (FPC) in Boulder, CO.

To minimize cost and risk, the Whipple OCC and SOC facilities and data systems will be integrated directly into the existing facilities and systems used to operate Chandra.

The OCC data system consists of the Online System (ONLS) for real-time commanding and telemetry monitoring, and the Off Line System (OFLS) for mission planning and command management. These systems have a common heritage to systems operating in the NASA/MSFC Huntsville Operations Support Center. Adapting the Chandra systems to Whipple will require relatively modest changes. The ONLS was designed to support multiple missions with minimum modifications. Required changes are limited to a new telemetry and command database, new telemetry displays and command scripts, and mission-specific characteristics and constraints. In addition, Space Link Extension modifications to the Chandra system are already planned in support of the DSN, and CCSDS File Delivery Protocol (CFDP) will be added for Whipple. Since Chandra is operated via the DSN, all network interfaces to DSMS are in place and functional.

The SOC data system is based on the Chandra Science Data System, which consists of a pipeline data processing system, a flexible, searchable data product archive, and supporting infrastructure. Adapting the Chandra system to Whipple will require only localized changes to the data receipt and science mission planning functions. The pipeline architecture allows plugging in Whipple-specific software tools, while the archive can readily be adapted to host the new database schema.

The OCC, which will house the engineering unit (EU) of the focal plane instrument, will interface to the Ball FPC via a dedicated T1 link to access the flight software maintenance facility (SMF). Interfaces from the ONLS to the SMF and EU will be established early in Phase C to provide operations support for developing and testing flight software and operations products. Maximum use is planned of the OCC and SOC data systems during S/C and instrument development, I&T, end-to-end (ETE) testing, and for other data flow tests. Since both systems require only limited modification, we will reduce risk by using them early to check out data flow and validate data formats, operational products and procedures.

The SAO approach to developing and maintaining ground software, including the operational software at the OCC and the science processing components at the SOC, will follow existing Chandra practices, and will include software quality assurance, verification and validation, and configuration management.

Integration of the Whipple ground system hardware into the Chandra facilities will be straightforward and will require a minimum of new equipment. The Whipple OCC system will consist of a new string of Linux servers packaged as a single rack and located in the Chandra OCC computer room. The SOC hardware will be implemented using standard Linux components integrated into the existing Chandra science facilities. Software maintenance for the ground system during the mission will also be integrated with the existing Chandra effort, thus minimizing cost. The OCC and Chandra SOC computer facilities are secure locations and will not require any changes as a result of the integration of the Whipple mission.

G.8 MISSION OPERATIONS


The SAO team brings a wealth of science and mission operations experience to the Whipple mission. The Chandra X-ray Center, which is the first combined science and mission operations center outside of a major NASA center for a mission of Chandra class, has been notably successful. In addition, SAO has conducted science operations for Einstein, ROSAT, and TRACE, among others.

The Flight Operations Team (FOT) located at the OCC is responsible for performing flight mission planning, conducting real-time passes, performing real-time and long-term monitoring and trends, and responding to anomalies. The
FOT interfaces with the Engineering Operations Team (EOT), the Ball spacecraft developers at the FPC who maintain the FSW. The EOT also provides engineering technical support to the OCC with emphasis on anomaly resolution. The Science Operations Team (SOT) at the SOC provides the weekly science mission plan, processes science telemetry to produce science data products, monitors science instruments, provides expertise to maintain the focal plane instrument flight software, archives data and products, analyzes data, and delivers products to the PDS. The PI and the science team provide scientific direction to the mission through the SOC and are responsible for analyzing and interpreting data, coordinating ground-based follow-up observations, and providing outreach to NASA and the public through the Whipple Education and Public Outreach (EPO) function.

**Mission Operations Development.** The OCC and SOC will be staffed during Phase B to develop the mission operations concept and to specify system requirements for ground and flight mission operations and data analysis. Maximum use is planned of the ground data systems during Phase C/D in support of spacecraft and instrument development and testing. We reduce risk by planning early system use with an expert staff to ensure thorough data flow checkout, and to gain valuable experience with data formats, operational products, and procedures.

During I&T, the OCC will coordinate closely with the I&T team to ensure tight configuration management and coordination of the command and telemetry databases used for I&T and at the OCC. The EOT will support the FOT in the development of operations products and by providing training in spacecraft subsystems and their operations.

The SOT will support Phase C/D S/C and instrument activities to ensure capture of operational knowledge, ground calibration and performance data; develop instrument FSW maintenance procedures; and gain operational experience during ETE and other data flow tests.

By the completion of Phase C/D, the FOT, SOT, and EOT will be staffed and certified to operate the mission under the direction of the Mission Operations Manager (MOM). As has been done with Chandra, cross-training will be used extensively to mitigate the risk of staff turnover during the mission and to maximize expertise.

**Commissioning.** During the launch and commissioning phase, Whipple mission operations will be conducted from the OCC with expanded support from the EOT. Following transfer of mission responsibility to the OCC at launch vehicle separation, the Operations team will carry out the Whipple Commissioning Phase Plan to activate and check out each S/C subsystem and the focal plane instrument. During this phase, the MOM will oversee integrated flight, flight engineering, ground, and science operations activities. The EOT staff will be located at the OCC, with backup support at the FPC, led by the Ball Aerospace Lead Engineer. Following commissioning, the EOT will transition to on-call operations engineering support from the FPC.

The FOT, with support from the EOT, will conduct the commissioning phase over a 30-day period. Operations during the first two weeks will be conducted 24 hours per day, and will then transition to once-daily 8-hour passes for the remainder of the phase. During commissioning, all S/C subsystems are checked out, the pointing and star camera are calibrated, out-gassing reaches an acceptable level, and the science instrument is calibrated and sees first light.

**Flight Operations.** Following commissioning, science operations begin with the SOC providing the OCC with an observing plan sufficient for two weeks of observing. The FOT combines the plan with the upcoming DSN schedule and relevant mission constraints, and uses the OFLS to generate a weekly schedule and associated command loads. Standard tracking passes are conducted with the DSN once every 4 days for 4 hours to dump the SSR and perform safety and health monitoring. A DSN beacon pass is conducted 2 days after each normal pass, with the frequency tones used to signal both high priority source detections and anomalous Focal Plane Sensor (FPS) conditions. In the event of a beacon-signaled source, the SOT is notified so they can initiate ground-based observing as soon as possible.

The FOT conducts other routine activities including engineering data trending, orbit determination, maintenance of on-board ephemeris, DSN pass planning, regular operations
reporting, development and maintenance of required flight and ground procedures and scripts, and operation of the OCC ground system. Flight software is maintained by the FPC, with software patches passed to the OCC for uplink. In the event of an anomaly, the FOT responds in accordance with previously developed procedure, and contacts the MOM, who coordinates with the FPC and leads the anomaly response team.

**Science Operations.** The SOC receives all science telemetry, performs automated pipeline processing to science products, archives the telemetry and products, and monitors and trends science instrument behavior. During the early stages of the mission, emphasis will be placed on monitoring and updating the onboard algorithms for detecting and triggering from signals. We expect a number of parameter changes to the FPS flight software during the first 2 to 3 months of the mission, followed by periodic updates. The SOT is responsible for maintaining the FPS software using the EU at the OCC, and for supporting instrument anomaly resolution. As the mission progresses and better understanding of the total data set is gained, full reprocessing of the mission science data is expected approximately every year.

The SOT maintains the calibration of the instrument and monitors the performance of the detectors and overall system as the mission progresses.

**G.9 TECHNICAL RISKS**

Our key challenges have been defined and assigned priorities based on our risk analysis described in section H.3. Our top technical risk, FPA electronics maturity, is being mitigated through a separately funded PIDDPP to be completed by the end of FY07. The SAO team will build breadboards and engineering units to increase the FPA TRL to at least 6 by the end of the PIDDPP study. We have identified alternate vendors for these components and will be able to make a decision to proceed during Phase A as a result. Key Whipple technical risks are summarized in Table G-18. More detailed information on the Whipple risk process is available in section H.3, Risk Management and Mitigation Plans.

**G.10 TRADE STUDIES**

The Whipple team performs trade studies by balancing cost, schedule, and technical risk to identify where the optimum “knee-of-the curve” is for overall best value. Owing to Kepler heritage, very few trade studies are required for the Whipple mission. Parametric analyses identify areas that may need to be excluded because of cost constraints. Table G-19 provides a snapshot of the trade studies we propose for the Whipple design concept study. We selected each trade study based on the potential risk and benefits to Whipple. During Phase A and the Phase B bridge, we concentrate on system architecture trades that result in confirming the system level requirements that meet the Whipple science objectives. Following SRR, subsystem requirement and implementation trades for those changes from the Kepler design are completed by PDR. Our trade study evaluation criteria are based on NASA’s Greenbook, “Designing for Performance,” in which the goal is to obtain the lowest cost and risk for a given level of performance.

### Table G-18. Whipple Key Technical Challenges Prioritized by Risk Score.

<table>
<thead>
<tr>
<th>Risk Score (L/I)</th>
<th>Risk Item Description</th>
<th>Comments/Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/3</td>
<td>FPA Module/Readout electronics (SIDECAR) maturity</td>
<td>Continue PDDIP/I&amp;RD efforts to characterize performance. Reach TRL 6 prior to PDR. Early build and test of EM FPA and SIDECAR. Complete EM before design and fab of FM. Conduct early thermal tests.</td>
</tr>
<tr>
<td>3/3</td>
<td>Primary optics schedule</td>
<td>Hold early Inheritance Review, maintaining build-to-print approach. Implement lessons learned from Kepler procurement. Fund as long-lead procurement.</td>
</tr>
<tr>
<td>2/4</td>
<td>Maintain build-to-print effort</td>
<td>Establish solid science and mission requirements baseline within build-to-print capabilities. Hold early Inheritance Review. Establish waiver process with PI approval for deviations.</td>
</tr>
<tr>
<td>2/2</td>
<td>Field Flattener Lens fabrication</td>
<td>Provide Kepler lens specs, SOW, and lessons learned as starting point for Whipple.</td>
</tr>
</tbody>
</table>

Top Program Risk as shown in Section H.3 and Foldout H-1.

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