Spitzer Mission Operation System
Planning for IRAC Warm-Instrument Characterization

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Introduction

- The paper described how the Spitzer Mission Operations System (MOS) planned and executed the Infrared Array Camera (IRAC) Warm Instrument Characterization (IWIC) phase between Spitzer’s cryogenic mission and its warm mission.
  - The MOS is divided into the flight and ground systems.
  - The MOS also contains the people, teams, processes and procedures used to operate the mission

- IWIC was done with existing processing and procedures.

- The modifications that were made were in response to the differences of the characterization phase compared to normal phases before and after.

- The primary two categories of difference were:
  - unknown date of execution due to uncertainty of knowledge of the date of helium depletion
  - the short cycle time for data analysis and re-planning during execution.

- The planning and design had to be done in parallel with normal operations

- The paper also described the re-planning we had to do following an anomaly discovered in the first days after helium depletion.
The Spitzer Space telescope was launched on 25 August 2003 with a prime Cryogenic Mission Requirement of five years.

The In Orbit Checkout (IOC) and Science Verification (SV) mission phases were conducted for a period of 90 days.

The helium depleted on 15 May 2009, ending the prime mission and starting the Infrared Array Camera (IRAC) Warm Instrument Characterization (IWIC) followed by the extended mission.

The Extended Warm Mission is approved for two years with a pending proposal for an additional two-year extension.
IWIC Design Margin

<table>
<thead>
<tr>
<th>Mission Phase</th>
<th>Prime Cryogenic</th>
<th>Planned Standby Mode</th>
<th>IWIC</th>
<th>Extended Warm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Total Duration</td>
<td>5 years</td>
<td>3 days</td>
<td>42 days</td>
<td>2 years</td>
</tr>
<tr>
<td>Margin within Total</td>
<td>n/a</td>
<td>1 day (33%)</td>
<td>8.4 days (20%)</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Three science instruments

- **IRAC – Infrared Array Camera**
  - Bands: 3.6 µm, 4.5 µm, 5.8 µm, and 8.0 µm

- **MIPS – Multi-band Imaging Photometer**
  - Bands: 24 µm, 70 µm, and 160 µm

- **IRS – Infrared Spectrometer**
  - Bands: 5.2 µm – 14.5 µm, 9.9 µm – 19.6 µm, 14.0 µm – 38.0 µm, and 18.7 µm – 37.2 µm

In the Cryogenic Mission, only one instrument was on at a time for a sequence duration of one to three weeks.

- Primary mirror operates between 5.6 K and 12 K.

In the extended Warm Mission, only two bands of IRAC, 3.6 µm and 4.5 µm, will produce valid science data.

- Primary mirror operates at ~26 K
The emphasis for the IWIC was to characterize the IRAC performance at the warmer operating temperature.

No change in spacecraft performance was expected at the warmer temperature, so no repeat of IOC activities were needed.

Only routine maintenance activities were planned for the spacecraft.

During the month-long IWIC, teams had to work extended shifts.
The IRAC warm instrument characterization consisted of a set of on-orbit tests and observations with five primary objectives:

1. **To check the functionality of IRAC at ~30K**
2. **to determine the best operating parameters**
3. **to characterize properties of the data such as noise and artifacts**
4. **to collect calibration data to determine the dark bias, flat-field, linearity and other required calibrations to convert the data from raw data number to flux-calibrated images**
5. **to perform representative science observations to inform the observing community of the capabilities of warm IRAC**
IWIC driving requirements
- Verify that all observatory subsystems are nominal
- Verify that warm IRAC can take data
- Set the operating parameters in the data taking blocks to support nominal operation of the warm IRAC
- Determine that the data taken with the warm instrument, after deployment of the updated sci2 block library, can be calibrated

Mission constraints
- 2 work shifts
- Shifts would cover 7 days per week
- Telecommunications passes (1 every 12 hours) unlike IOC continuous coverage
- Relative timed sequences due to the date of helium depletion being unknown
- Each sequence was built to a fixed length that could later be trimmed to fit telecommunications allocations
- Avoid bright objects during the idle time
- Shorter sequences allowed rapid turn-around for data analysis for sequence dependencies
- While still building Prime mission Cryo sequence start to pre-build IWIC sequences
Legend:
--- new position
not required
The start of planning May 08
- *Mission Operations System Design Team (MOSDT) meetings*
- *Flight Engineering Team (FET) meetings*
- *Table-top design reviews*
  - Design exercise to walk through the MOS plan and detailed schedule for IWIC

Published a Preliminary IWIC Mission Plan December 08

The science observations planned for the first year of warm operations were approved by end of December 2008

Formal review was conducted January 09
- *The project received concurrence to proceed with the plan*

Final IWIC Mission Plan April 09

IWIC Exit Review July 09
IWIC Implementation

- Several different types of sequence products were used during IWIC and the beginning of the warm extended mission.
  - *Mini-sequences, each 12 to 24 hours long*
  - *One week-long absolute-timed sequence for the last part of IWIC*
  - *Absolute-timed sequences for the warm extended mission could not be pre-built, and were built completely during the latter part of IWIC*

- All of the sequence products related to IWIC itself were built in advance, to the highest level of maturity possible.

- During IWIC itself, the mini-sequences were modified, according to plan, to respond to actual results.

- Telecommunication allocations were scheduled that allowed flexibility for sequence execution.

- During IWIC repackaging, timelines were defined to support building sequences with dependencies.
• Science block library (commands to set parameters in the IRAC instrument)
  – Planned changes from the Prime Cryo Mission parameters
    • For IWIC two versions were built
      1. No-op version instead of commands to set parameters in the IRAC instrument
      2. Version containing the final IRAC parameters for Warm Mission

• The only types of work anticipated during IWIC were:
  – Changing the mini sequence length to fit the telecommunications allocation.
  – Changing targets because the original targets may no longer be in the Operational Pointing Zone (OPZ).
  – Changing the setting for the IRAC instrument based on data results from previous mini sequence execution.

• During IWIC execution, the MOS teams had to start building sequencing for the nominal warm mission in parallel with the development of IWIC sequences.
A temperature-control anomaly was discovered immediately after the execution of the first IWIC mini sequence.

The firmware was unable to correctly control the temperature of the IRAC instrument, at the new warmer temperature.

Commanded the spacecraft to standby mode to allow time to resolve the anomaly.

The problem was a digital-to-analog converter used to convert the commanded temperature set point was physically only twelve bits wide.

- The documentation and software on the ground specified sixteen

The effect was to silently truncate (i.e. set to zero) the most significant four bits of the commanded value.

The fix was to patched the flight software to shift the offset and range of the digital-to-analog converter so that only the least-significant twelve bits were needed to specify the desired temperature set point.
• The process of building, testing and approving the software patch took about one month.

• During the patch development IRAC was turned back on, we let its temperature float and made some science observations.

• Because of the month delay we combined two twelve-hour mini sequences per day into a single twenty-four-hour mini sequence.

• This allowed most of the mission operations teams to complete their work during prime shift, although they still worked seven days per week.
  
  – *The trade-off was a slower response time to change mini sequences based on flight events.*
### Planned vs. Actual by Mission Phase

<table>
<thead>
<tr>
<th>Mission Phase</th>
<th>Prime Cryogenic</th>
<th>Planned Standby Mode</th>
<th>IWIC Overall</th>
<th>IWIC Post-Anomaly Only</th>
<th>Extended Warm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Total Duration</td>
<td>5 years</td>
<td>3 days</td>
<td>42 days</td>
<td>42 days</td>
<td>2 years</td>
</tr>
<tr>
<td>Margin within Total</td>
<td>n/a</td>
<td>1 day (33%)</td>
<td>8.4 days (20%)</td>
<td>8.4 days (20%)</td>
<td>n/a</td>
</tr>
<tr>
<td>Actual</td>
<td>5.5 years</td>
<td>2 days</td>
<td>71 days</td>
<td>39 days</td>
<td>n/a</td>
</tr>
<tr>
<td>Actual Margin within Total</td>
<td>n/a</td>
<td>1 day (33%)</td>
<td>-30 days (-71%)</td>
<td>3 days (7.1%)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

(+ anomaly)
Conclusions

- IWIC was completed within the six weeks and accomplished all objectives. There were no further anomalies or large disruptions to the plan.

- By modifying the IWIC planning and execution after the one-month delay due to the IRAC firmware anomaly, the goal was accomplished.
  - The IWIC Plan was well understood and documented
  - Rehearsals and advance product build reduced complexity
The research and development described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

A large number of people from the Spitzer project, support organizations at the Jet Propulsion Laboratory, the Lockheed Martin Space Systems Company, and the Spitzer Science Center at the California Institute of Technology contributed to the development of the designs and operations processes described in this paper.

We would like to express our appreciation to all of them.
Orion's Dreamy Stars

A colony of hot, young stars is stirring up the cosmic scene in this new picture from NASA's Spitzer Space Telescope. The image shows the Orion nebula, a happening place where stars are born. The young stars dip and peak in brightness due to a variety of reasons. Shifting cold and hot spots on the stars' surfaces cause brightness levels to change, in addition to surrounding disks of lumpy planet-forming material, which can obstruct starlight. Spitzer is keeping tabs on the young stars, providing data on their changing ways.

The hottest stars in the region, called the Trapezium cluster, are bright spots at center right. Radiation and winds from those stars has sculpted and blown away surrounding dust. The densest parts of the cloud appear dark at center left.

This image is a combination of data from Spitzer and the Two Micron All Sky Survey (2MASS). The Spitzer data was taken after Spitzer's liquid coolant ran dry in May 2009, marking the beginning of its "warm" mission. Light from Spitzer's remaining infrared channels has been color-coded: 3.6-micron light is green and 4.5-micron light is red. 2MASS 2.5 micron light is blue.
Back-up Material
## Mission Phases

<table>
<thead>
<tr>
<th>Phase</th>
<th>Start and End Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch</td>
<td>2003-08-25</td>
</tr>
<tr>
<td>IOC and SV</td>
<td>2003-08-25 / 2003-12-01</td>
</tr>
<tr>
<td>Prime Cryogenic</td>
<td>2003-12-01 / 2009-05-15</td>
</tr>
<tr>
<td>Planned Standby</td>
<td>2009-05-15 / 2009-05-16</td>
</tr>
<tr>
<td>IWIC Overall</td>
<td>2009-05-16 / 2009-07-27</td>
</tr>
<tr>
<td>Extended Warm Approved</td>
<td>2009-07-27 / 2011-12-31</td>
</tr>
<tr>
<td>Extended Warm Proposed</td>
<td>2012-01-01 / 2013-12-31</td>
</tr>
</tbody>
</table>
In 1998, the science objectives for the Spitzer mission were defined as:

- Deep surveys of oldest galaxies
- Evolution and structure of ultra-luminous galaxies and quasars
- Search for Brown Dwarfs
- Evolution of stellar disks and planetary systems

For the extended warm, IRAC-only mission, the new science objectives are:

- Study properties of extra-solar planets
- Study galaxies during the first one billion years after the Big Bang
- Complete census of the galaxy for young stars
- Determine cosmic distance scale in the local universe
The primary mirror is 85 cm in diameter. It is made of beryllium and was cooled to between about 5.6 K and 12 K, depending on the instrument in use. The field-of-view angle of the telescope is 32′ (32 arcminutes). The focal length is 10.2 m. The total mass of the spacecraft at launch was 950 kg, including 50.4 kg of liquid helium cryogen.

Spitzer is in a heliocentric, Earth-trailing orbit. It follows the Earth around the Sun. Its orbit is slightly more elliptical than the Earth’s, and most of the time it is farther away from the Sun than the Earth is, so it slowly recedes from Earth at about 0.1 AU/yr.

- Current Orbit Information (Geocentric)
  - Distance = 125, 515, 752 km (~0.84 AU)
  - One-way light time = 418.687 s (~6m:59s)
  - Right Ascension (EME J2000) = 75.35 deg
  - Declination (EME J2000) = 22.63 deg
The spacecraft uses its on-board pointing control system to shade itself with its solar arrays for reasons of thermal control. As such, at any given time, it can see only about 31.5% of the full sky. This area is called the Operational Pointing Zone (OPZ). There are two zones of the sky around the ecliptic poles that are always in view. Objects in the ecliptic plane are in view for two periods of forty days each per year.