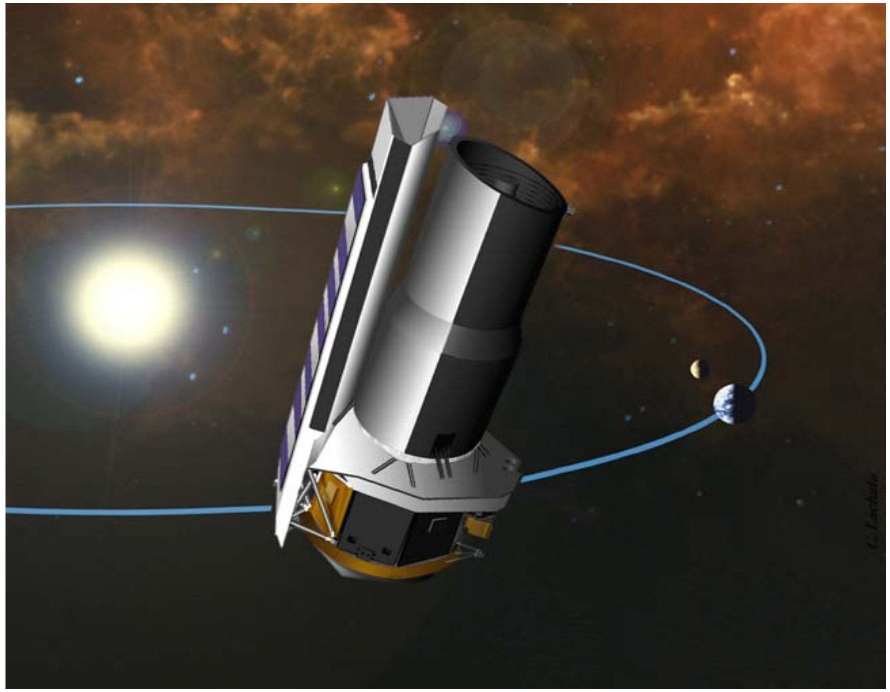

Spitzer Space Telescope
In-Orbit Checkout and Science Verification Operations

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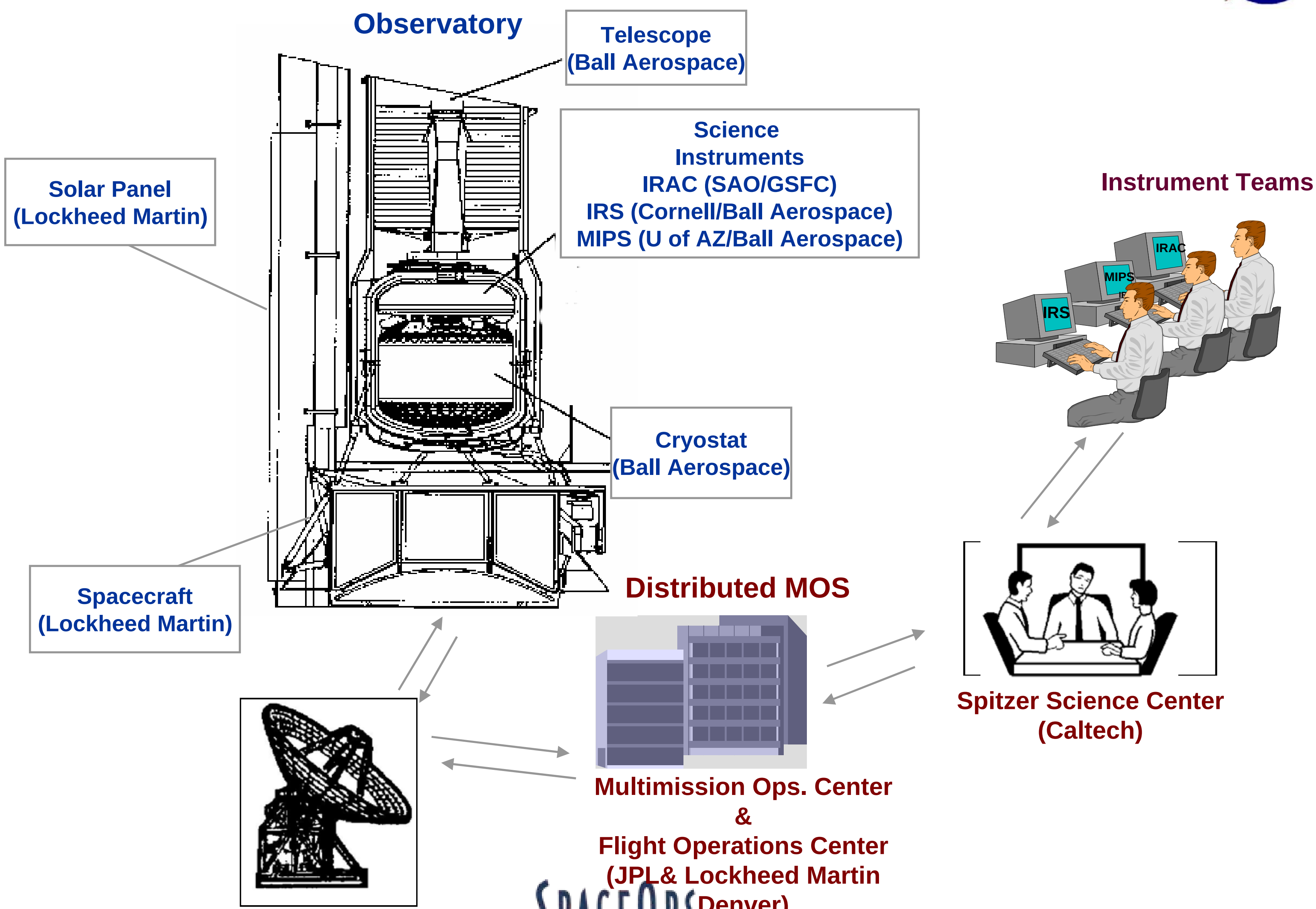
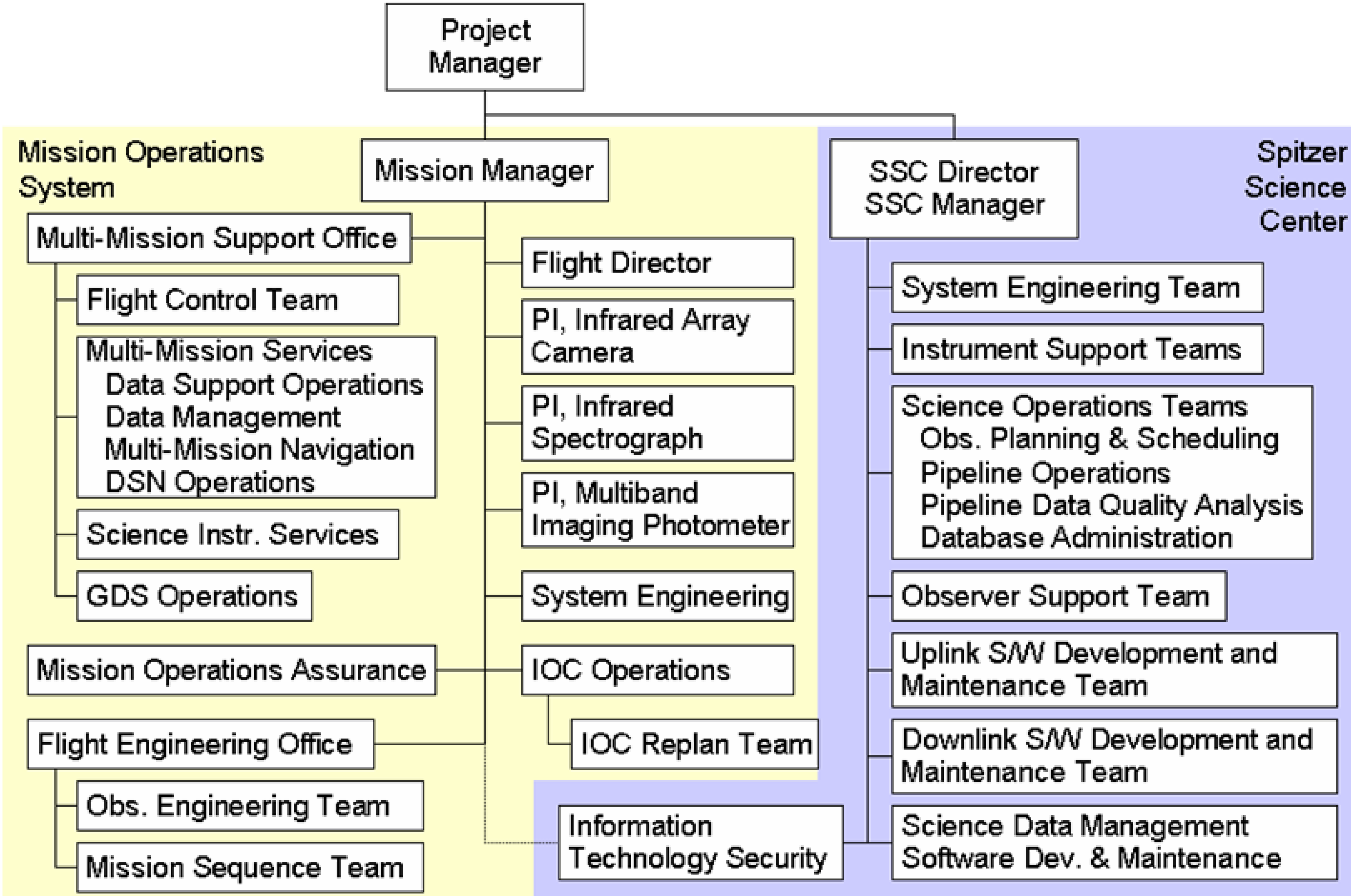
Mission Overview

- Infrared Observatory launched August 25, 2003 for a 5 year mission
- Earth trailing heliocentric orbit
- Liquid-helium radiatively-cooled observatory
  - *85-cm telescope, diffraction-limited @ 6.5 µm*
  - *Imaging, spectroscopy from 3-180 µm*
  - *Three Instruments use large-format infrared detector arrays:*
    - Infrared Array Camera (IRAC) – Dr. Giovanni Fazio (Harvard)
    - Infrared Spectrometer (IRS) – Dr. Jim Houck (Cornell)
    - Multiband and Imaging Photometer (MIPS) – Dr. George Rieke (University of Arizona)
  - *Innovative mission concept*
    - Warm launch into a heliocentric orbit
    - Vapor-cooled telescope; cooling enhanced using cryostat heater
- Completes NASA's Great Observatories; is a cornerstone of the Origins Program

System Architecture and Team Members



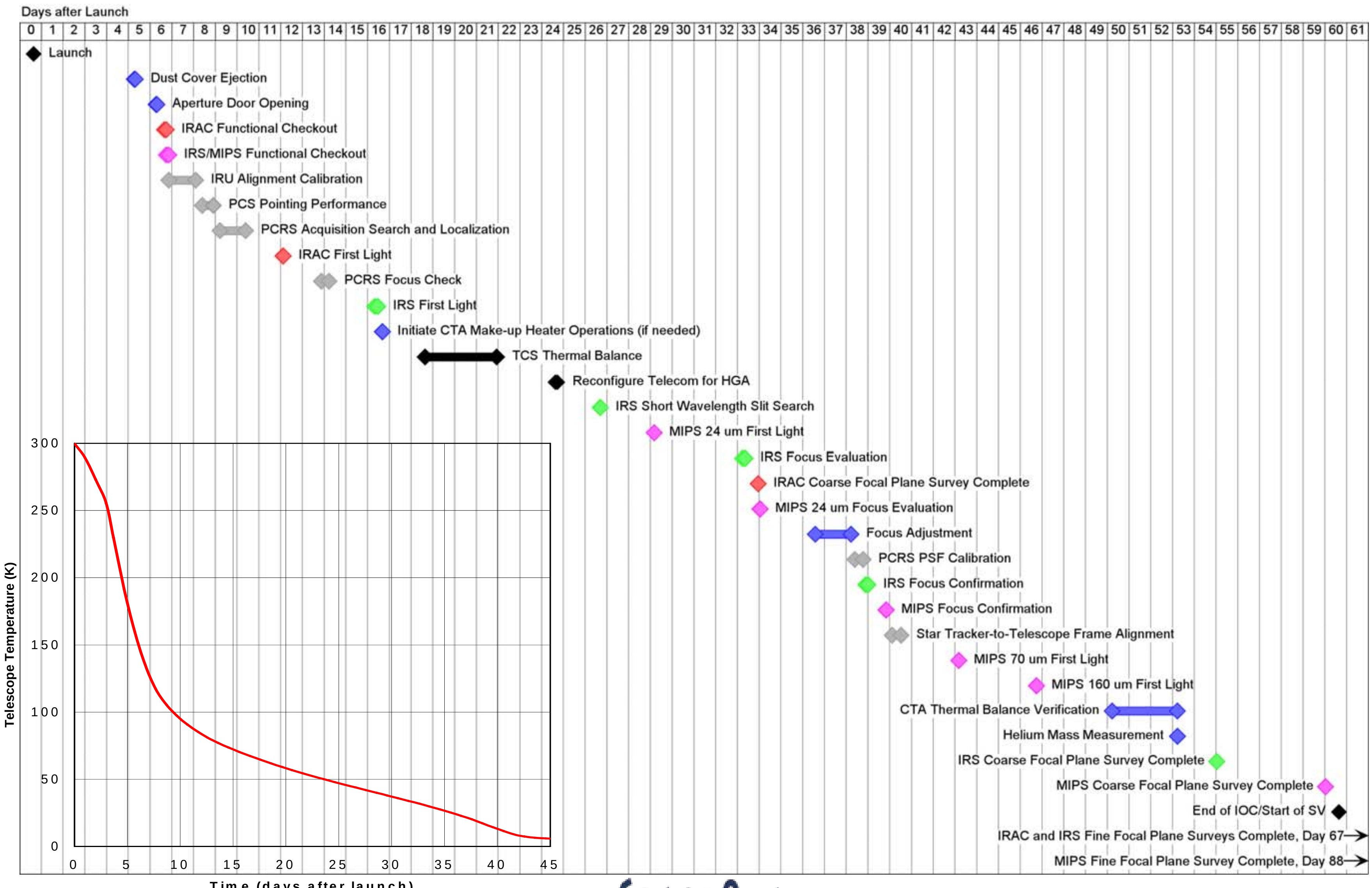
IOC/SV Project Organization



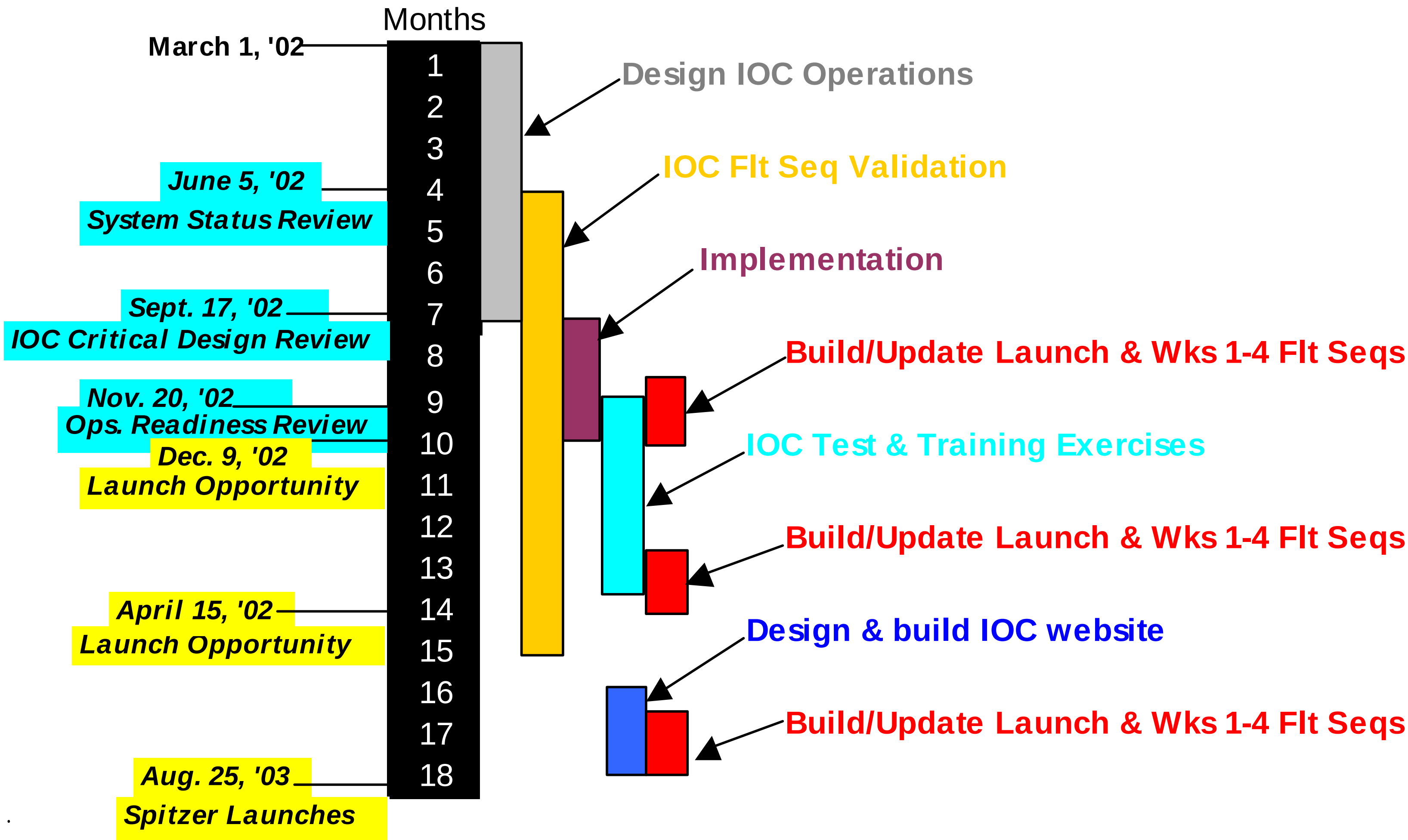
In-Orbit Checkout and Science Verification

- Two phases that carry out the activities required to commission SPITZER observatory for routine science operations
  - *In Orbit Checkout (IOC)*
    - To start at Launch +4.5 hours
    - Bring the Facility on-line safely and expeditiously
    - Verify the functionality of the instruments, telescope, and spacecraft to meet the Level 1 requirements
  - *Science Verification (SV)*
    - Characterize the Observatory in-orbit performance
    - Demonstrate Observatory capability for autonomous operations
    - Conduct early release observations
    - Exercise the ground systems software, processes, and staffing sufficiently to commission the Facility for routine operations
- The goal of IOC/SV was to carry these activities out as quickly as possible to retain as much helium as possible
  - *Complete IOC in 60 days*
  - *Complete SV within 90 days after launch*

IOC Timeline Highlights



IOC/SV Development Timeline (the challenge)



Operating Conditions During IOC and SV

- In IOC the Observatory condition continually evolving:
  - *Must successfully complete critical events (dust cover eject & aperture door open)*
  - *Changing telescope temperature*
  - *Pointing control system (PCS) performance continually improving*
  - *Instrument pointing continually refined*
  - *Re-focus telescope if necessary (critical decisions must be made for focus adjustment)*
- Ground Operations expected to be intense compared to nominal operations.
- IOC/SV operations need flexibility in scheduling activities
- The IOC/SV operations team must be able to make changes quickly
  - *Operating in a distributed environment - JPL, Lockheed Martin (Sunnyvale & Denver), Ball, Spitzer Science Center (SSC) and PI Sites*

IOC Operational Features and Characteristics

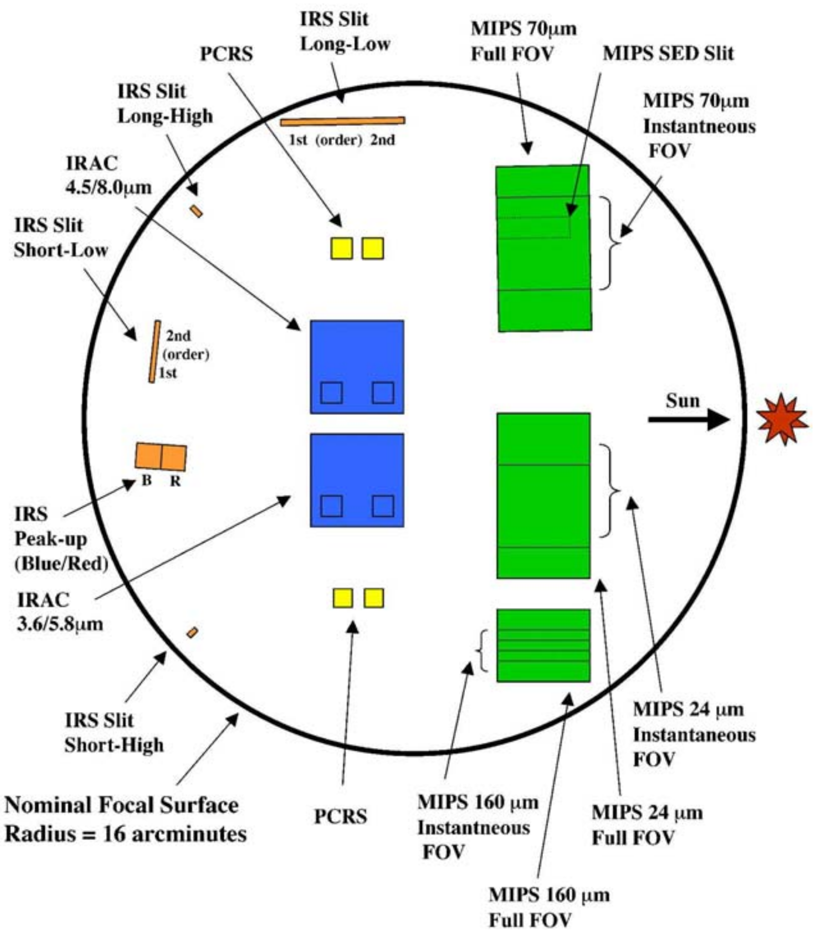
- Spitzer Observatory designed for easy operability
  - *Heliocentric orbit*
    - No eclipses or occultations
    - Excellent sky access and visibility - sun angle between 80° and 120°
    - Continuous viewing within 10° of ecliptic poles.
  - *IOC ground operations were interactive and event-driven*
  - *IOC real time communication strategy*
    - Uplink sequences via “Load & Go” strategy
    - Ground commanded downlink after every instrument campaign/spacecraft engineering event
    - 100% ground station coverage
    - Time between events spent pointing the high gain antenna to the earth
  - *Instrument Operations*
    - Campaign durations ranged from hours to days
    - Campaigns tied to telescope temperature requirement
    - One instrument “ON” at a time
  - *Engineering activities required at specific intervals woven throughout IOC/SV*
    - Scheduled internal to instrument campaigns when required

IOC Operational Features and Characteristics (continued)

- IOC Unique Ground Processes
  - *Focal Plane Survey (complicated with interdependent activities)*
  - *Focus Adjust*
  - *IOC Sequence Development*
  - *3 day update process (to responding to evolving/changing events on the spacecraft)*
  - *Quick Turn-around (24 hour) Process*
- Replan Team needed to focus on IOC/SV–for quick and many changes
- Transition to Nominal Operations processes in SV
  - *Transition to nominal operation exercised in steps*
  - *Ground Transition*
    - Schedule change to generating week long sequence loads (with 2 downlinks/day)
    - Instrument operations responsibility moved to Science Center
    - Integration of on-board activities moved to the Science Center
  - *On-Board Transition*
    - Week long loads - inserted 12 hour "gap" into last three SV loads for real-time commanding in response to on-going activities
    - Less than 100% ground antenna coverage

Focal Plane Survey

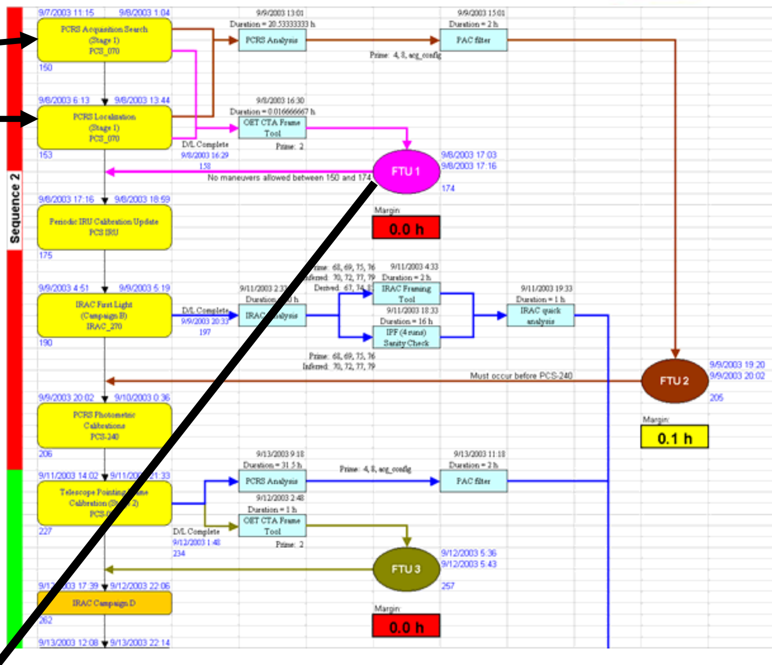
Nominal Field-of-View Locations Projected onto the Sky



- Purpose
  - *Determine the mapping of celestial coordinates to pixel coordinates for each instrument focal plane.*
- Approach
  - *Execute a series of coarse surveys for each array, prior to focus adjustment.*
  - *Once the telescope is focused and the focal plane is stable, a series of fine surveys are executed.*
  - *The coarse survey and fine survey strategies and procedures are similar, except that the coarse surveys typically require fewer iterations.*
- Coarse surveys
  - *Provide enough pointing capability to proceed with other early activities, but with relaxed requirements, so that they are not driven by the need to change focus or to have a stable, cold telescope.*
- Fine surveys
  - *Provide the ultimate pointing capability for each array.*
- Ground Processes
  - *Updated on-board configuration file containing FOV coordinates on focal plane.*

Frame Table Update (FTU) Process
(in support of the Focal Plane Survey)

ID	Task_Name	CAID	LGA	Duration (min)	Start_Date (UTC)	Finish_Date (UTC)
146	Level_1_reqt_PCS_accuracy			0	9/7/2003 5:57	9/7/2003 5:57
150	PCRS_Acquisition_Search_Stage_1	PCS_070	+Y	829	9/7/2003 11:15	9/8/2003 1:04
151	PCRS_2_Mini_Scan_Part1	PCS_XXX	+Y	239	9/8/2003 1:04	9/8/2003 5:03
152	PCRS_2_Mini_Scan_Part2	PCS_XXX	+Y	70	9/8/2003 5:03	9/8/2003 6:13
153	PCRS_Localization_Stage_1	PCS_070	+Y	451	9/8/2003 6:13	9/8/2003 13:44
154	75_K			0	9/8/2003 9:19	9/8/2003 9:19
155	Campaign_downlink_acquisition_and_playback_initiation			42	9/8/2003 13:44	9/8/2003 14:26
156	Downlink_PCS_data_FTU_1_and_2			63	9/8/2003 14:26	9/8/2003 15:29
157	**Frame_Table_Update_Process_FTU_1_and_2**			1667	9/8/2003 15:29	9/9/2003 19:16
158	Downlink_latency_FTU_1_and_2			60	9/8/2003 15:29	9/8/2003 16:29
159	Ground_analysis_of_PCS_070_data_FTU_2			1232	9/8/2003 16:29	9/9/2003 13:01
160	OET_CTA_frame_tool_FTU_1			1	9/8/2003 16:29	9/8/2003 16:30
161	Generate_mini_spreadsheet_FTU_1			1	9/8/2003 16:30	9/8/2003 16:31
162	Review_mini_spreadsheet_FTU_1			1	9/8/2003 16:31	9/8/2003 16:32
163	Approve_mini_spreadsheet_FTU_1			1	9/8/2003 16:32	9/8/2003 16:33
164	Build_acq_config_file_FTU_1			1	9/8/2003 16:33	9/8/2003 16:34
165	OSTL_integrity_check_FTU_1			14	9/8/2003 16:34	9/8/2003 16:48
166	Command_approval_FTU_1			15	9/8/2003 16:48	9/8/2003 17:03
167	PAC_filter_FTU_2			120	9/9/2003 13:01	9/9/2003 15:01
168	Generate_mini_spreadsheet_FTU_2			30	9/9/2003 15:01	9/9/2003 15:31
169	Review_mini_spreadsheet_FTU_2			60	9/9/2003 15:31	9/9/2003 16:31
170	Approve_mini_spreadsheet_FTU_2			30	9/9/2003 16:31	9/9/2003 17:01
171	Build_acq_config_file_FTU_2			60	9/9/2003 17:01	9/9/2003 18:01
172	OSTL_integrity_check_FTU_2			60	9/9/2003 18:01	9/9/2003 19:01
173	Command_approval_FTU_2			15	9/9/2003 19:01	9/9/2003 19:16
174	Frame_Table_Update_1	PCS_FTU_1		13	9/8/2003 17:03	9/8/2003 17:16



							7	
				Planned (computed automatically)				
Activity	**Team**	**Contact Person**	**Time until U/L**	**Start UTC**	**End UTC**	**Start PDT**	**End PDT**	**Duration**
PCS-070 (Stage I; 2, 4, 8)								
Downlink	OET / FCT		2.6 h	9/8/2003 14:26	9/8/2003 15:29	9/8/2003 7:26	9/8/2003 8:29	1.0 h
D/L-to-TDS	DSOT		1.6 h	9/8/2003 15:29	9/8/2003 16:29	9/8/2003 8:29	9/8/2003 9:29	1.0 h
ground processing margin								
OET CTA frame tool	OET		0.6 h	9/8/2003 16:29	9/8/2003 16:30	9/8/2003 9:29	9/8/2003 9:30	0.0 h
IT / PCRS Analysis								
PAC filter								
IRAC Framing Tool								
MIPS Framing Tool								
IPF processing								
IRAC quick analysis								
IRS analysis / comparison								
MIPS analysis for Multi-Run								
run IRAC Derived Framing Tool								
run MIPS Derived Framing Tool								
generate MiniFrame file & MCR	OET		0.6 h	9/8/2003 16:30	9/8/2003 16:31	9/8/2003 9:30	9/8/2003 9:31	0.0 h
review MiniFrame file	OET, IPF, IT, SSC		0.5 h	9/8/2003 16:31	9/8/2003 16:32	9/8/2003 9:31	9/8/2003 9:32	0.0 h
CCB to approve MiniFrame file	MOS CM		0.5 h	9/8/2003 16:32	9/8/2003 16:33	9/8/2003 9:32	9/8/2003 9:33	0.0 h
build ACG.cfg file	OET		0.5 h	9/8/2003 16:33	9/8/2003 16:34	9/8/2003 9:33	9/8/2003 9:34	0.0 h
OSTL integrity check	OET		0.5 h	9/8/2003 16:34	9/8/2003 16:48	9/8/2003 9:34	9/8/2003 9:48	0.2 h
Command Approval	MOS MM		0.3 h	9/8/2003 16:48	9/8/2003 17:03	9/8/2003 9:48	9/8/2003 10:03	0.3 h
MARGIN:			**0.0 h**	9/8/2003 17:03	9/8/2003 17:03	9/8/2003 10:03	9/8/2003 10:03	
FTU 1 U/L	FCT		0.0 h	**9/8/2003 17:03**	9/8/2003 17:16	**9/8/2003 10:03**	9/8/2003 10:16	0.2 h

Data mapped from time-ordered listing, to frame table update data flow diagram, to detailed process activities & their durations. All information was in EXCEL.

Launch Activity Plan

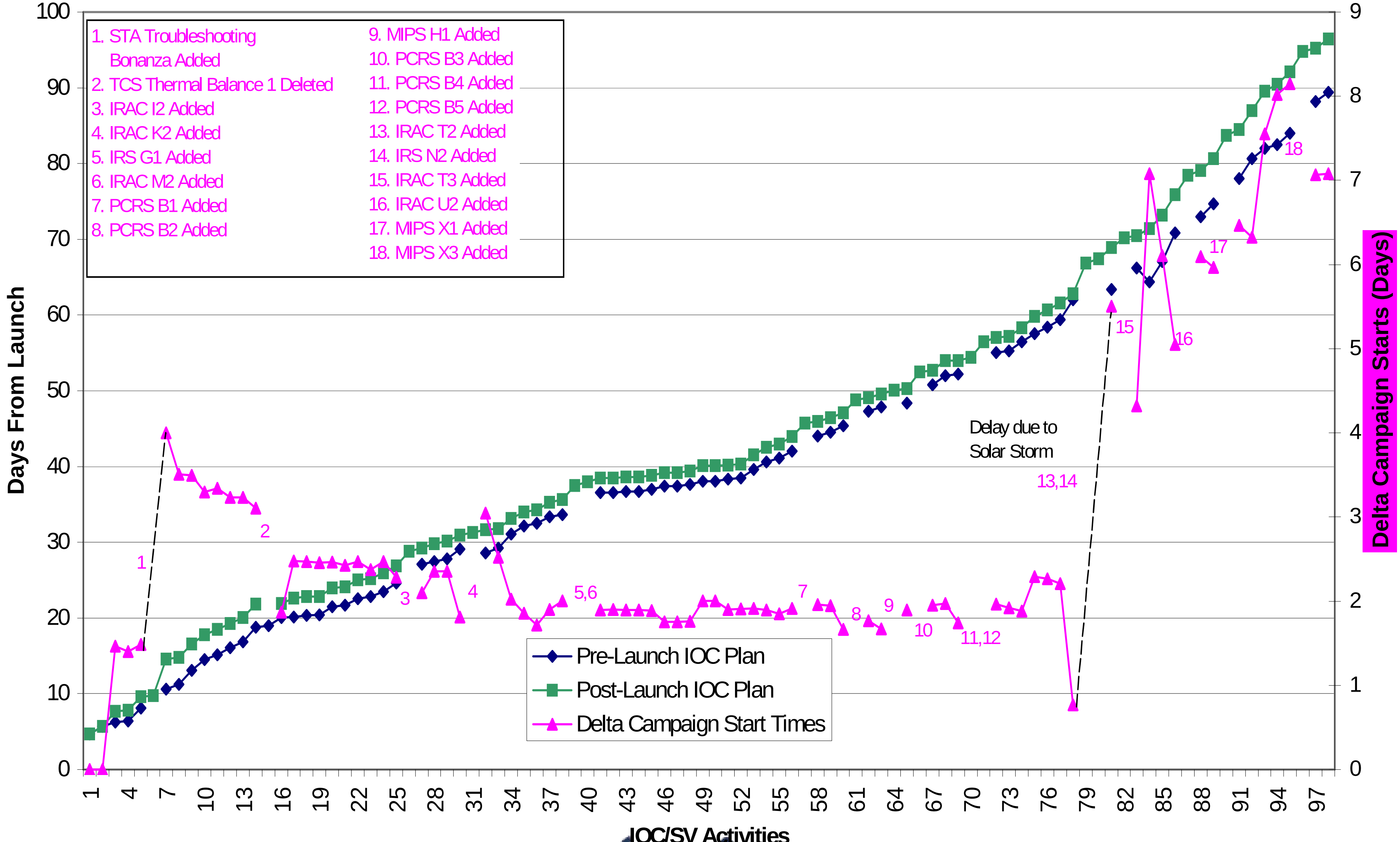
- The on-board plan (timeline) was altered 32 times prior to launch
  - *The instrument campaigns and spacecraft activities grew as they were built*
    - 20% instrument design margin began to disappear
    - S/C activity durations were increased multiple times
    - Reserve (Observatory idle time) was significantly reduced
- Below are the statistics we launch with including strategically placed reserve time relative to focus, the watershed event in IOC.

PRE-Launch Stats	Pre-focus IOC	Focus	Post-focus IOC	SV	Totals
	(days)				
Duration	36.56	1.88	23.56	30.00	92.00
CTA	0.21	0.13	3.07	0.00	3.41
IRAC	7.37	0.35	4.77	7.06	19.55
IRS	3.28	0.00	4.29	7.31	14.88
MIPS	0.92	0.00	3.55	8.50	12.97
PCS	10.01	0.36	3.09	1.86	15.33
SC	2.94	0.00	0.13	0.02	3.08
Ground	0.41	1.02	0.19	0.08	1.71
Total Activities	25.14	1.87	19.08	24.83	70.92
Margin/Reserve	11.42	0.01	4.48	5.17	21.08
Efficiency	69%	99%	81%	83%	77%

Observatory Performance

Date	Safemode/Standby	Reason	Time in mode	Comment
8/25/2003 (Launch)	Safemode Entry #1	Star tracker not allotted enough time to acquire	14 hours	At initial acquisition. Some IOC activities still performed during safemode.
8/27/2003	Safemode Entry #2	High drag torque on reaction wheel during momentum management checkout	4 days	Ejected dust cover and opened aperture door while in safemode.
10/23/2003	Standby Mode Entry #1	Global variable management issue in the IRS/MIPS combined electronics flight software	10.5 hours	Occurred during MIPS instrument campaign J
10/28/2003	Stand-Down (defacto Standby)	Large solar storm	2.4 days in stand-down before recovery started	Solar flux above 100 MeV.
11/12/2003	Safemode Entry #3	Incorrect system momentum check fault protection parameters uplinked prior to IRAC campaign V	22 hours	Parameters based on prelaunch analysis that did not account for current configuration of observatory
12/1/2003				End of SV

IOC Pre-Launch Plan vs. What was Flown



How efficiently did we operate?

FLIGHT Stats	Pre-focus IOC	Focus	Post-focus IOC	SV	Totals
	(days)				
Duration	38.46	1.90	22.38	35.54	98.29
CTA	0.24	0.05	2.99	0.00	3.28
IRAC	8.37	0.36	5.29	7.92	21.94
IRS	3.25	0.00	4.72	10.12	18.09
MIPS	0.95	0.00	4.16	10.98	16.09
PCS	11.51	0.92	3.67	2.40	18.50
Spacecraft	2.08	0.25	0.12	0.06	2.50
Ground	0.74	0.32	0.19	0.14	1.39
Total Activities	27.14	1.90	21.14	31.62	81.80
Idle Time	11.32	0.01	1.24	3.92	16.49
Efficiency	71%	100%	94%	89%	83%

IOC took 62.8 days to complete in flight vs 62 day prelaunch plan
SV took 35.6 days to complete in flight vs 30 day prelaunch plan

Major Challenges Faced

- Development
  - *Developing the IOC operations implementation plan beginning 9 months prior to launch with only a mission activity plan in place*
  - *Determining just how much flexibility was needed in IOC (given workforce constraints)*
  - *Getting the flight software and the ground software stable enough to test sequences prior to launch*
  - *Building IOC activities and testing them in the operations software test lab (OSTL)*
  - *Managing the complex IOC timeline (with ground constraints) quickly and accurately with no time or money to develop additional tools*
  - *The separation of science operations and mission operations created a challenge and was not the optimal organizational structure*
- Operations
  - *Moving from real-time command operations to the one-week absolute-timed sequences*

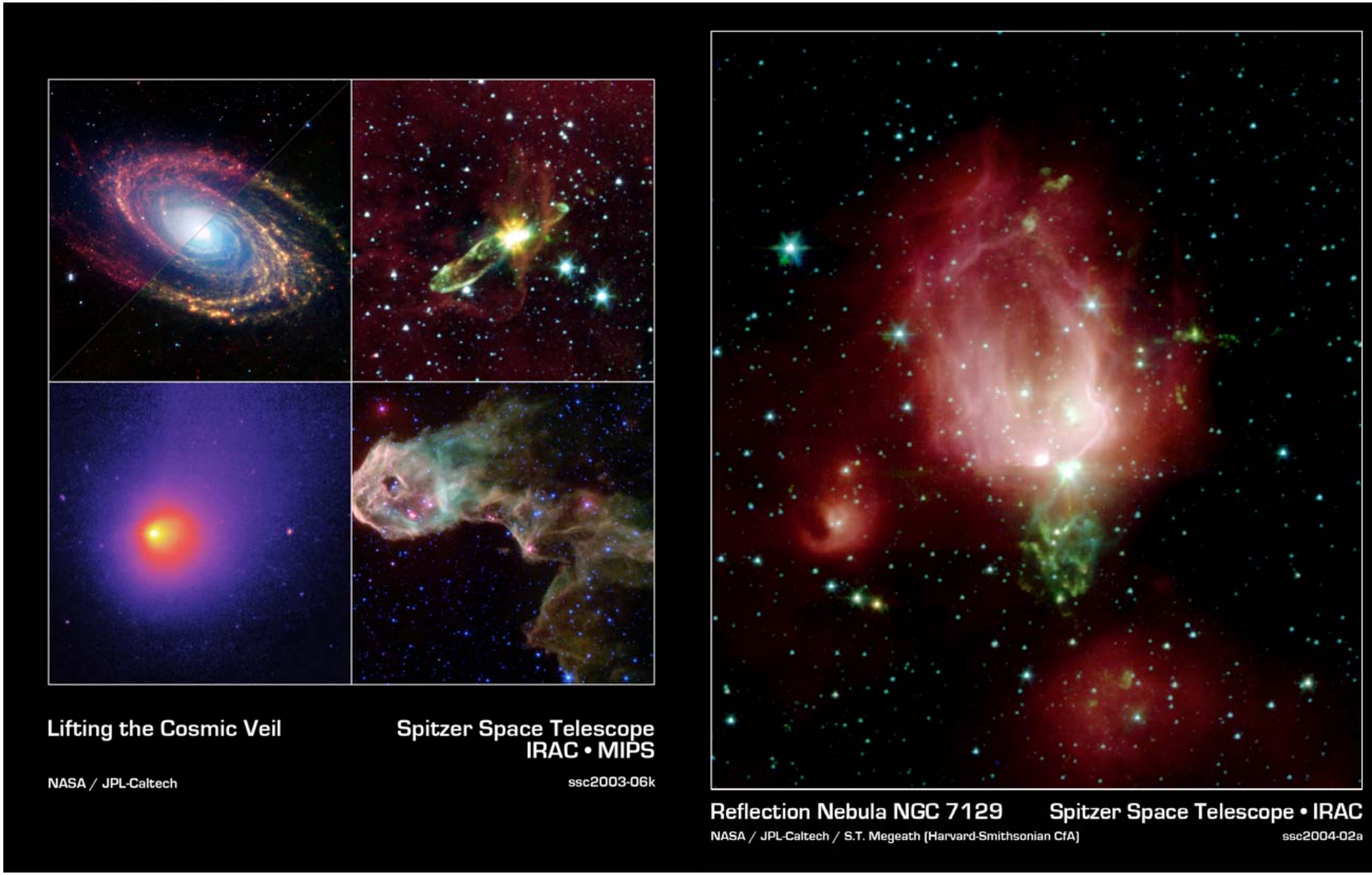
Lessons Learned

- Establish working group early to develop checkout plans.
  - *Take a top-down process approach.*
  - *Use as many of the nominal science operations processes as possible*
  - *Identify additional processes needed to address the unique IOC activities*
- Balance operational flexibility with ground station coverage
- Build and validate all sequences prior to launch
- Build science campaigns in “relative time”
- Build science campaigns with targets in the viewing zone for a reasonable period
- Strategically place reserve time in the timeline
- Pull together a team to focus on checkout replanning (during operations)
  - *Team members need to have following skillset: system engrineering, mission planning, mission design, sequending and spacecraft knowledge*
  - *Perform many test and training exercises*
  - *Dedicate a war room for checkout planning*
  - *Schedule two replan meetings per day*
- Develop a website with access to all important documentation, tools, forms, useful links, and daily status postings.

Conclusion/Summary

- For SPITZER IOC/SV operations turned out to be a significant and unique challenge. It was a bigger job than was expected.
  - Adequate time must be given to developing IOC/SV operations – at least 20 months
  - Develop the ground system to include the Checkout phase (no matter which team performs the work)
- Proper IOC/SV design and development requires a dedicated Team which needs to move into operations
- Build <u>all</u> your checkout sequences BEFORE LAUNCH
- Provide enough reserve in the timeline and strategically place it

On to the Science Phase …



These results are just beginning

http://sirtf.caltech.edu/