Spitzer Space Telescope

Unprecedented Efficiency and Excellent Science on a Limited Budget

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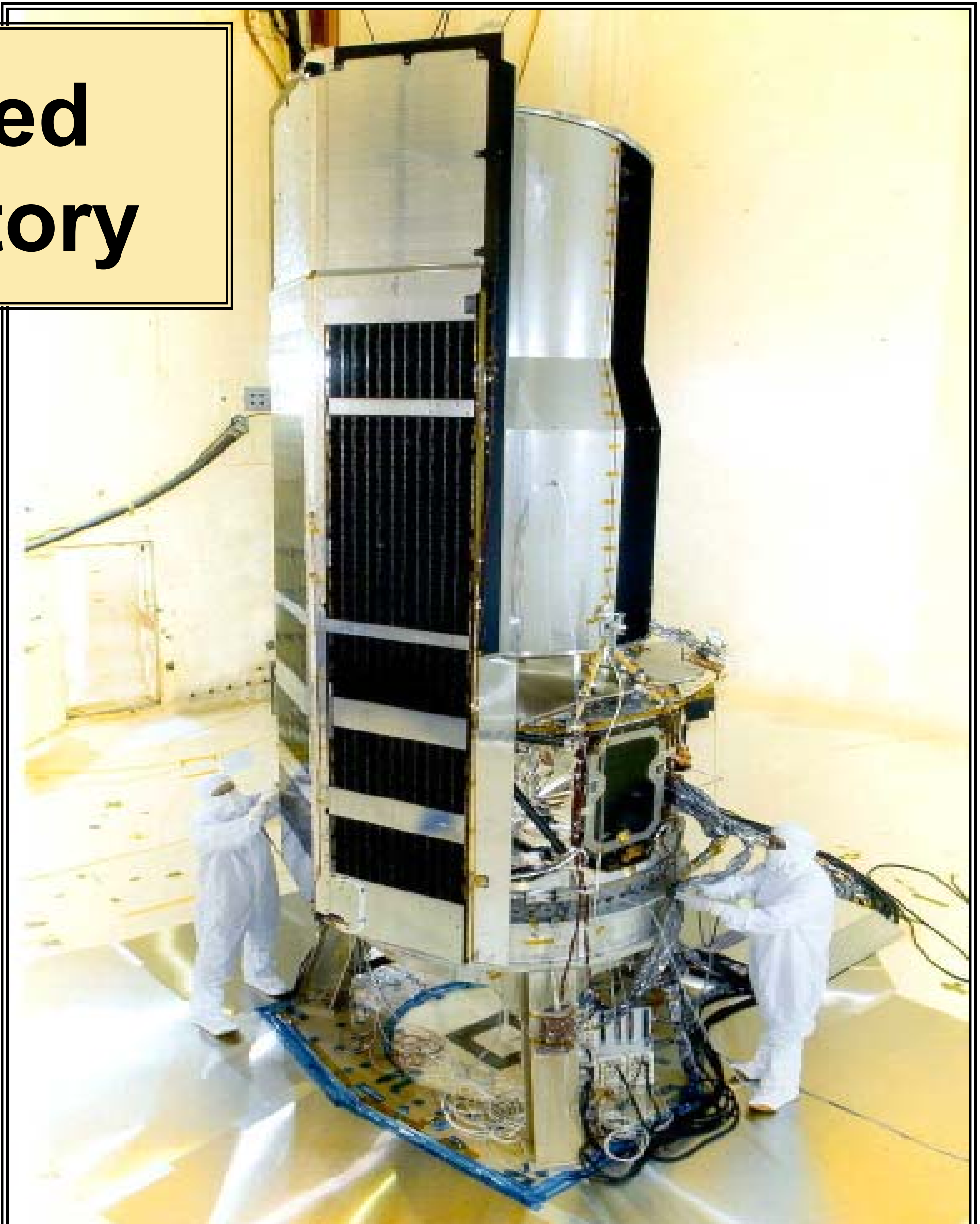
NASA's Infrared Great Observatory



Design of the observatory, instruments and operations concept were all driven by maximizing observing efficiency

→ Maximize science return during cryogenic mission

History

Ancient History

- SIRTF mission studies began in the late 1970s
- Shuttle InfraRed Telescope Facility
  - *Highly recommended in the 1979 NAS report*
  - *Repeated shuttle flights*
  - *1983 call for proposals for instruments*
- IRAS all-sky survey (1983)
  - *Substantial interest in follow-up observatory such as Spitzer*
- 1984 – SIRTF Instruments selected and plans made to build a free flying mission
- 1985 – Shuttle-based IRT flew, contamination issues
- Project became “Space Infrared Telescope Facility”

Instruments

3 cryogenically cooled science instruments

- InfraRed Array Camera (IRAC)
  - *PI: Giovanni Fazio, SAO*
  - *imaging @ 3.6, 4.5, 5.8, 8.0 μm*
- InfraRed Spectrograph (IRS)
  - *PI: Jim Houck, Cornell*
  - *Spectroscopy from 5.2-38μm*
- Multiband Imaging Photometer for Spitzer (MIPS)
  - *PI: George Rieke*
  - *imaging @ 24, 70,160 μm + low-resolution spectroscopy from 55-95 μm*

Mission Evolution

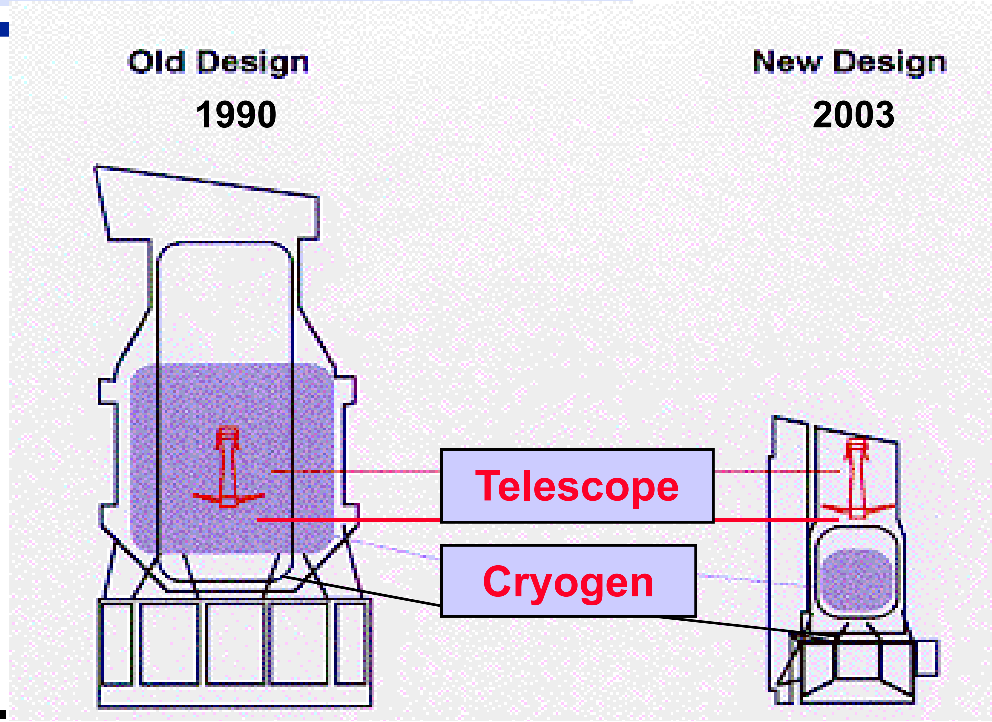
- Project nearly cancelled several times
- Major descope in early 1990s
  - *Led to two of the mission's most successful innovations*

1. Warm Launch

2. Heliocentric Orbit

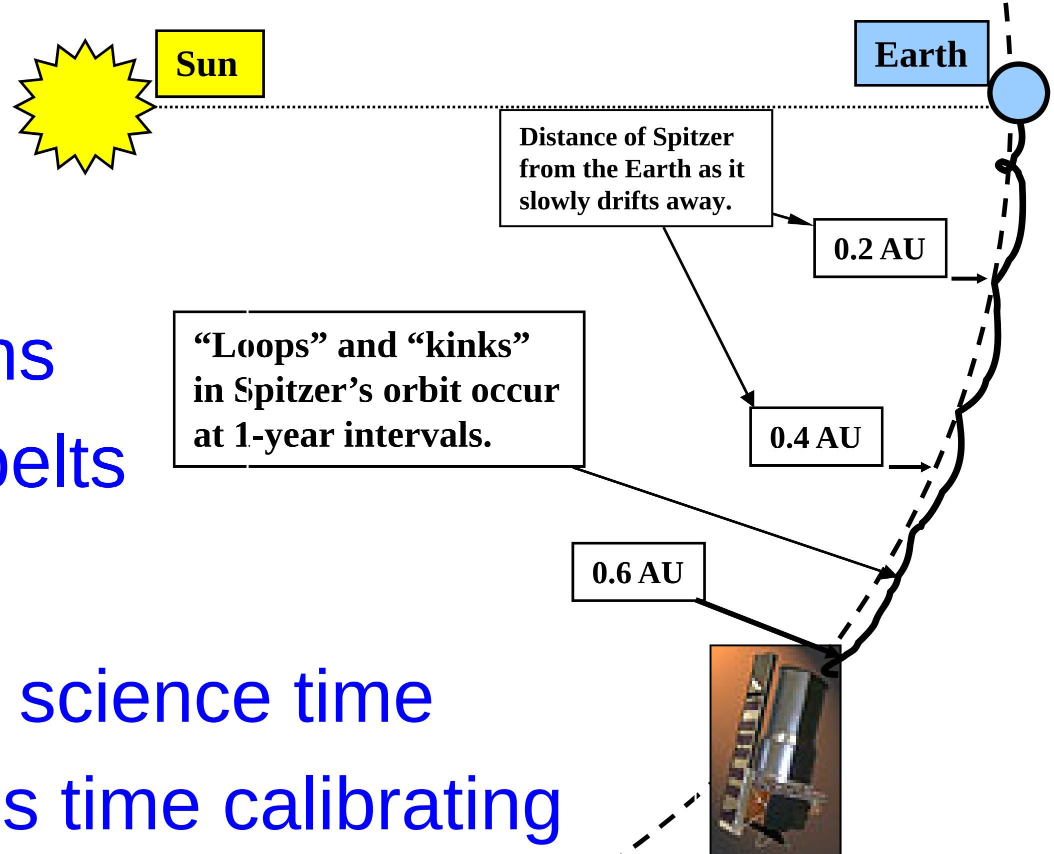
Warm Launch

- No reduction in telescope size
- No reduction in lifetime – 5 years
- Significant cost + weight savings



Cold launch	Architecture	Warm launch
Earth Orbit	Type of Orbit	Solar Orbit
5700 kg	Launch Mass	870 kg
3800 liters	Cryogen Volume	360 liters
Titan IV	Launch Vehicle	Delta II
~$400 M	Launch Cost	~$70 M
~$2.2 B	Development Cost	$0.74 B

Earth-Trailing Solar Orbit

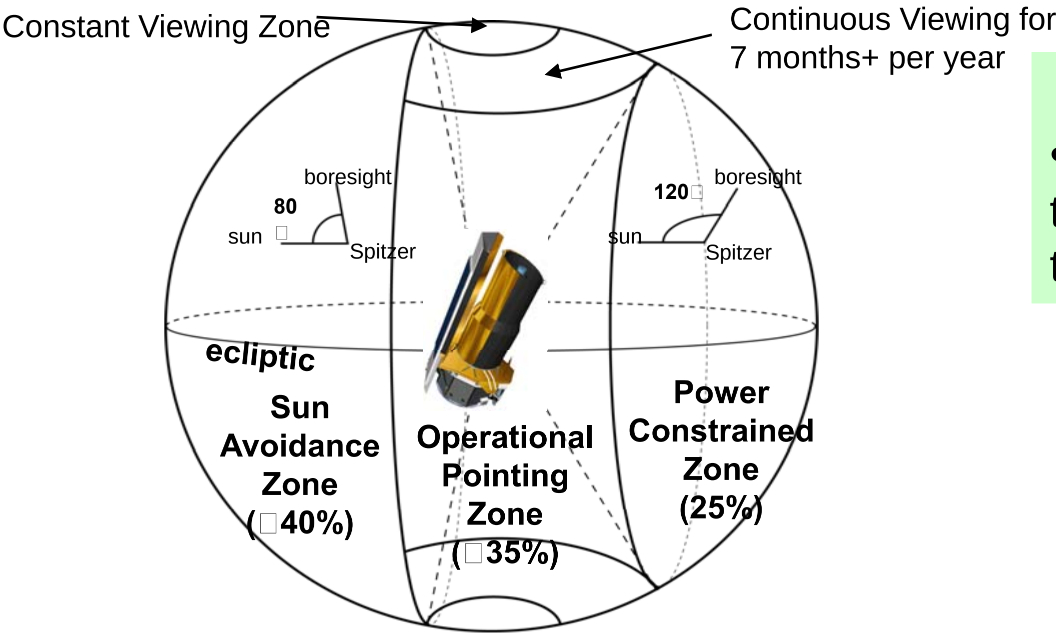


- Thermally Stable
- No earth occultations
- No earth radiation belts

→ Maximizes science time

Stability → less time calibrating

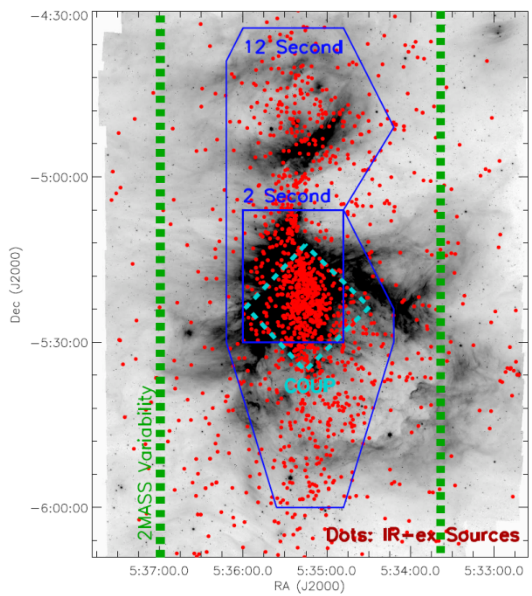
Sky Accessibility & Slewing



Efficient slewing

- Allows coverage anywhere in the OPZ on frequent timescales

YSOVAR program includes 1 square degree image of the core of ORION twice / day for 37 consecutive days to study variability in ~1000 young stellar objects



Sky Accessibility

- **Orbit enables >7000 hours observing per year**
- OPZ covers ~35% of the sky at any given time
- Given point on the sky remains visible for at least 40 days at a time
- **Allows continuous coverage for long periods or hundreds of hours of observing in a visibility window**

Modern History

- Launch – August 25, 2003
- Nominal Operations began December 1, 2003
- Cryogen depleted May 15, 2009
  - *day after Herschel launch … conservation of cryogen in space*
  - *36,463 hours of science in cryogenic mission*
- Warm Operations began July 28, 2009
  - *17,375 hours and counting for the warm mission*
- 54,000 hours in ~8 years of operation
  - *Would take ~20 years in near earth orbit*

Fun Fact: Mission Day 3,000 – Friday 11/11/11

Spitzer Team

- Jet Propulsion Laboratory
  - *Project Management & Science Office*
  - *Mission Operations*
  - *Observatory communication through Deep Space Network*
- Lockheed Martin – Denver
  - *Observatory Engineering Team*
- Science Operations + Outreach
  - *Spitzer Science Center, Caltech (IPAC)*
- Instrument Teams
  - *SAO, Arizona, Cornell, Ball Aerospace, NASA Goddard*

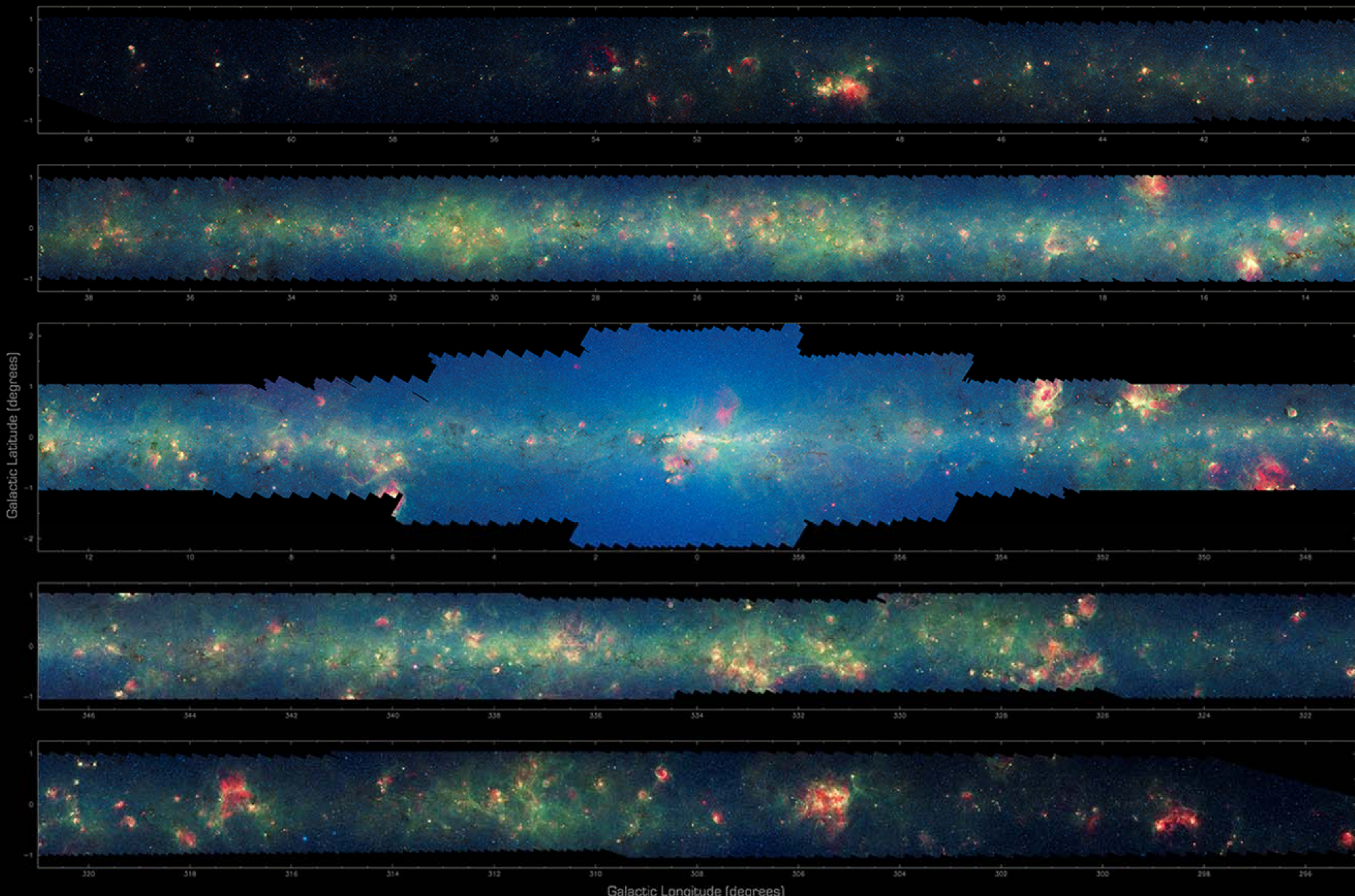
Cryogenic Mission

Overview

- Execute 7000 – 7500 science hours/year
- 700 – 800 proposals/year
  - *Observing, Archival and Theoretical research*
- Support ~250 PI programs annually
  - *GO, GTO, Archive, Theory*
- Support up to 10 quick-turnaround scheduling interrupts annually
- Spacecraft contacts every 12 hours
- Total Annual Budget ~$72 million
  - *Operations: $37 million*
  - *User Community: $35 million*
    - GO/GTO data analysis funding, Spitzer Fellowship program, Archival/Theoretical Research

Instruments

- Three instruments with a total of 2 moving parts
  - *MIPS scan mirror*
    - Provides freeze-frame imaging
    - Telescope slews continuously and the scan mirror compensates for the motion, ‘freezing’ the image
    - Very efficient mapping of large areas
  - *IRAC Shutter*
    - Not used - possible ‘closed’ failure mode identified before launch
- Instruments operate one at a time
  - *Parallel channels within an instrument do operate simultaneously*



The Infrared Milky Way: GLIMPSE/MIPSGAL **Spitzer Space Telescope • IRAC • MIPS**

NASA / JPL-Caltech / E. Churchwell (Univ. of Wisconsin), GLIMPSE Team & S. Carey (SSC-Caltech), MIPSGAL Team **ssc2008-11a**

Observing Modes

- Provide a limited, but powerful set of options
  - *Astronomical Observation Template (AOT)*
    - instrument, dithering and mapping parameters
  - *Targets*
    - single and multiple (cluster) targets for fixed and moving objects
- Astronomical Observation Request (AOR)
  - *AOT + targeting information → fully defined observation*
  - *AOR is the fundamental unit of Spitzer observing*
  - *AORs can be linked with observing constraints*

→ No ‘orphan modes’ that cannot be calibrated

→ Less time overall spent taking calibration data

Command Generation

- Software that provides the resource estimates for AORs also builds the commanding products for scheduling
  - *Very high fidelity time estimates when proposing*
  - *Supports a 1 – 1.5 phase proposal process*
- Original plan was a single phase proposal process
  - *Impractical to require all AORs with the proposal for large, complex programs*

→ Science user support still required to help scientists plan their programs and design AORs

→ Fewer resources overall than a full 2-phase process

Observing Cadence & Scheduling

- Instrument Campaigns
  - *IRAC → MIPS → IRS on a ~35 day cycle*
  - *Maximizes cryogenic lifetime (next slide)*
  - *Objects with shortest visibility windows are still accessible to all instruments*
- Time allotted to each instrument determined by selected proposals – driven by science, no quotas
- Spacecraft contacts scheduled twice/day
  - *Typically < one hour each*
- Period of Autonomous Operation – PAO
  - *Time between spacecraft contacts*

Scheduling

- Scheduled in one week blocks
  - *New 'master sequence' uplinked each week, along with scheduling modules to fill the week*
- Non-science observatory activities are minimal
- Schedulers are dedicated to maximizing every possible minute

  → *20-22 hours/day for science observations*

- No real time observing – schedule could be interrupted for high priority targets of opportunity
  - *Fastest turnaround was ~ 36 hours during cryo-mission*

Cryogen Management

- Mission cryogenic lifetime requirement was 2.5 years
- Original estimates were 4.9 years
  - *Telescope was cooled by vapor vented from the cryostat*
  - *Heat into Helium bath → telescope cools*
- MIPS required the coldest operating temperature
  - *Heat pulse was sent in advance of the MIPS campaign to reach the required temperature*
  - *MIPS 160um – 5.5 K 24 & 70um – 8.5 K*
  - *Cycle-2 implemented MIPS "warm" and "cold" campaigns*

→ Active temperature management increased the cryogenic lifetime to 5.5 years … +4000 hours!

Legacy Science Program

- 2.5 year mission → typical science cycle is too long!

  propose → observe → analyze → publish→ interpret → repeat
- Select large, public programs to execute early
- Require data products to be returned to the archive
- Criteria
  - *Large, coherent projects, not reproducible by any reasonable number of combination of smaller GO programs*
  - *General and lasting importance to the broad astronomical community with the Spitzer observational data yielding a substantial and coherent database*
  - *Data public domain immediately upon processing and validation, thereby enabling timely follow-up*

Legacy Science Program (2)

- 6 programs, 3160 hours selected in November 2000
  - *Launch scheduled for 2001 when call for proposals issued*
- Executed in first year of the mission
- Legacy programs again solicited in Cycles 2 – 5
- Legacy enhanced data products are some of the most popular data available in the Spitzer Heritage Archive

SHA @ NASA/IPAC Infrared Science Archive (IRSA)

http://sha.ipac.caltech.edu/applications/Spitzer/SHA

Pipeline Processed Data

- Basic data product from SSC pipelines is the BCD
  - *BCD = Basic Calibrated Data*
- Multiple versions of the BCD created in some cases to support different science cases
- Also provide PBCD products (post-BCD) and data analysiss tools
- > 80% of investigators start their science analysis with the BCD data products

Community Funding

- Cryogenic mission ~40% project budget to community
  - *$30 – 35 million/year   GO, Archive, Theory, Fellows, GTO*
- GO Data analysis funding determined formulaically
  - *Total observing time*
  - *Number of Instruments/Modes used*
  - *Complexity of the different observing modes*
  - *Base amount to cover page charges and a computer*
  - *Economies of scale for larger programs*
  - *Creation of enhanced Legacy data products*
  - *Institutional overhead is NOT a factor*

Impact of $$ Formula

- No budget proposals
- No financial review committee
- Special funding requests not supported

How Funding is Issued

- Funding issued at the start of the cycle
  - *Feasible with the stability and reliability of Spitzer*

- 85% of the funding is issued by the Jet Propulsion Laboratory as Research Support Agreements (RSAs)

- Research Support Agreement (RSA)
  - *New funding instrument created to support Spitzer*
  - *Fixed cost, advance funded, contract that looks like a grant*
  - *Low overhead (< 5%)*
  - *Only deliverable is a final report*
  - *3-year period of performance*

Warm Mission

Reinventing Spitzer

Challenge

Identify a warm mission operations model to execute an outstanding science mission that could be operated for substantially less than the cryogenic mission

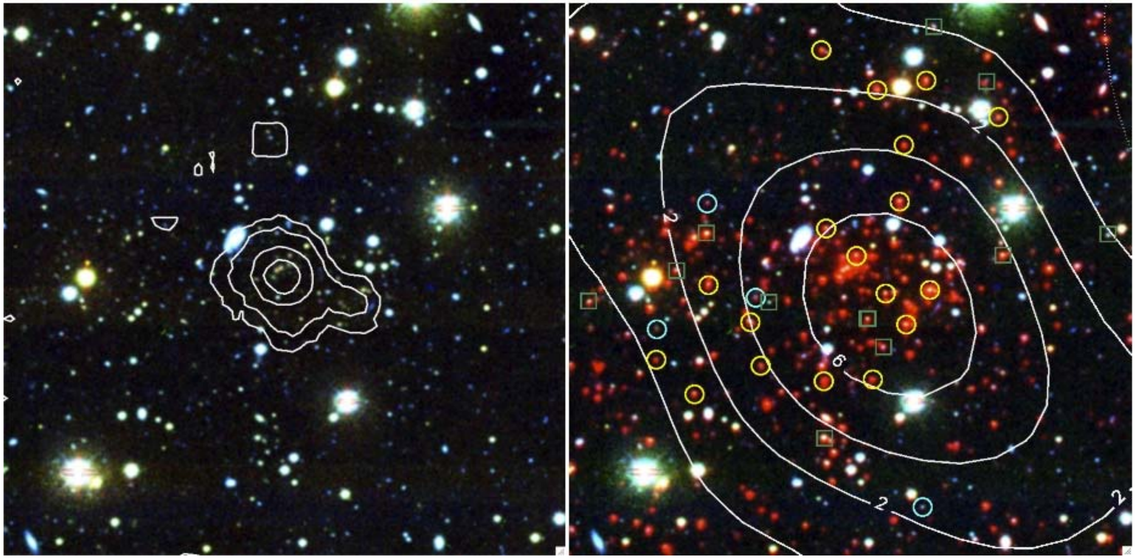
- Initial Goal: 50% reduction in the budget
- Final Reality: greater than 65% reduction

Warm Mission Capabilities

- IRAC 3.6, 4.5 μm
  - *Too warm for MIPS, IRS, IRAC 5.6, 8.0 μm*
- Two-thirds of the papers published during the cryogenic mission utilized IRAC data
- Retains cryo-mission stability, sensitivity, mapping speed and observing efficiency
- Remains a community observatory supporting a broad range of science
- Science hours per year has actually increased
  - *7850 hours/year for first two years*
- IRAC all-the-time enables new time domain science

Warm Mission Science

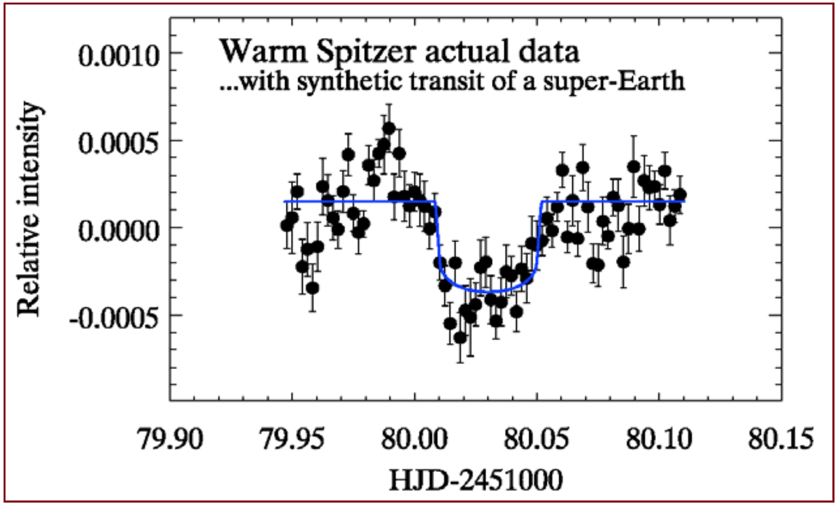
High Redshift (z > 1) Cluster - South Pole Telescope



Left panel: Optical 4' x 4' color image (riz); X-ray overlay
Right panel: False color optical (ri) + warm IRAC (3.6 um).
SZ contours overlaid. (Brodwin et al 2010)

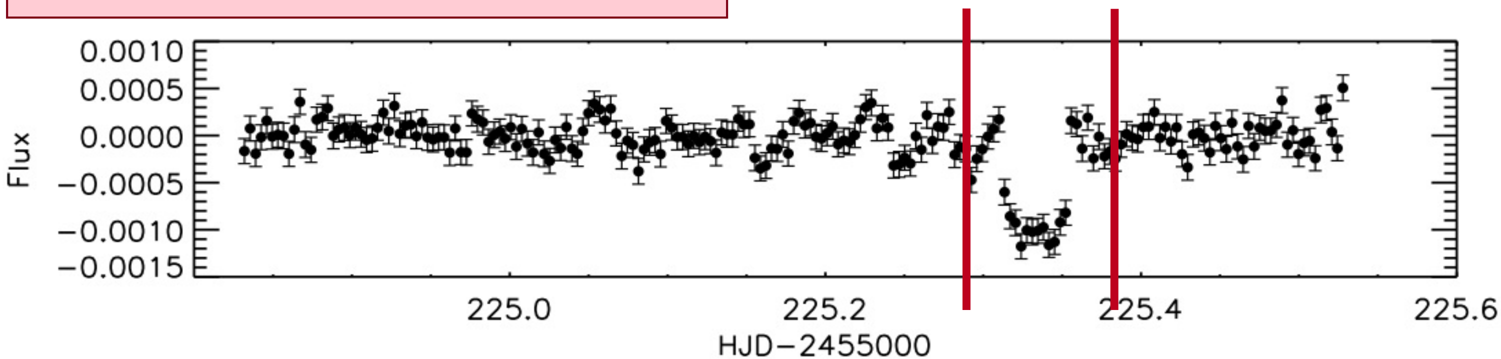
Simulating "Earth" Detections

Solar-type star
2.5 earth radius planet



(3.6 microns, Deming et al. 2010)

M-dwarf GJ-436
1.5 earth radius planet



(Ballard et al. 2011)

Obvious Changes

- Mission Operations
  - *No longer need to monitor and manage the cryogen*
    - One thermal engineer
- Science Operations
  - *No longer need to support IRS and MIPS operations*
    - < 20% of SSC Staffing

The observatory doesn't care which instrument is running. The instruments were never operated in parallel, only serially.

➔ Harder to find savings in mission operations than in science operations.

Guiding Principles

1. **Maximize the scientific return of the mission.**
2. **Spitzer is a community observatory.**
3. **Minimize the risk to the health and safety of the observatory.**
4. **Accept additional risk to science.**

Community Input

- Cryogen depletion expected Jan – June 2009
- Most obvious way to cut costs was to reduce the number of programs supported
  - *Exploration Science programs > 1000 hours*
- Fall 2006 – Recruited Steering Committee
  - *External scientists, variety of disciplines*
  - *Each had their own sub-committee*
  - *Wrote white papers on what science would be enabled by > 1000 hour programs*
- Invited the subcommittees and the community to a workshop in June 2007
  - *"Science Opportunities with the Spitzer Warm Mission"*

Workshop Results

Feedback was substantive and specific.

- Every subcommittee discussed exciting possible proposals that wouldn't have been possible during the cryogenic mission
- Exploration Science programs embraced
  - *proposal size should be 500 hours*
- Must continue to support small programs
- Select peer reviewed science
  - *don't do an HDF-like program for the transition*
- No strong opposition to doing more of the proposal review remotely to save money on the review

What Changed

- Reduced the number of PI programs we support from ~250 to ~60 per year
  - *Introduced Exploration Science programs, 6000 hrs/yr*
  - *Small (<50 hrs), Large (50-500 hrs), ~1800 hrs/yr*
- Panel portion of proposal review done by telecon instead of face-to-face meeting
  - *TAC meets face-to-face to recommend large/ES programs*
  - *Saves ~$250k/year in direct costs for the review*
- No high/medium impact targets of opportunity supported in GO programs
  - *Will support one/year, must be submitted as DDT proposal*

What Changed (2)

- Spacecraft contacts every 24 – 48 hours
- Fewer late schedule changes
- Most software ‘frozen’
- Fewer staff for performance analysis, anomaly recovery – dropped quality analysis review
- Halved Public Affairs/Outreach staffing
- Community Funding
  - *Ended Spitzer Fellowship Program*
    - Spitzer research now supported by Hubble Fellowships
  - *No Archive/Theory programs*
  - *Substantially reduced data analysis funding*
    - Mean $/hour was $3000 - $4000 during cryo mission, now $700
    - No funding for programs < 20 hours

Current Paradigm

- Execute 7000 – 8000 science hours/year
- 150 – 200 proposals/year
  - *Observing, Archival and Theoretical research*
- Support ~50 PI programs annually
  - *100% time is for general observers*
- Support 1 quick-turnaround scheduling interrupt annually
- Spacecraft contacts every 24 - 48 hours
- Total Annual Budget ~ $22 million
  - *Operations: $18 million*
  - *User Community: $4 million – all for General Observers*

Staffing Summary

◆ Substantial staffing reductions across the project

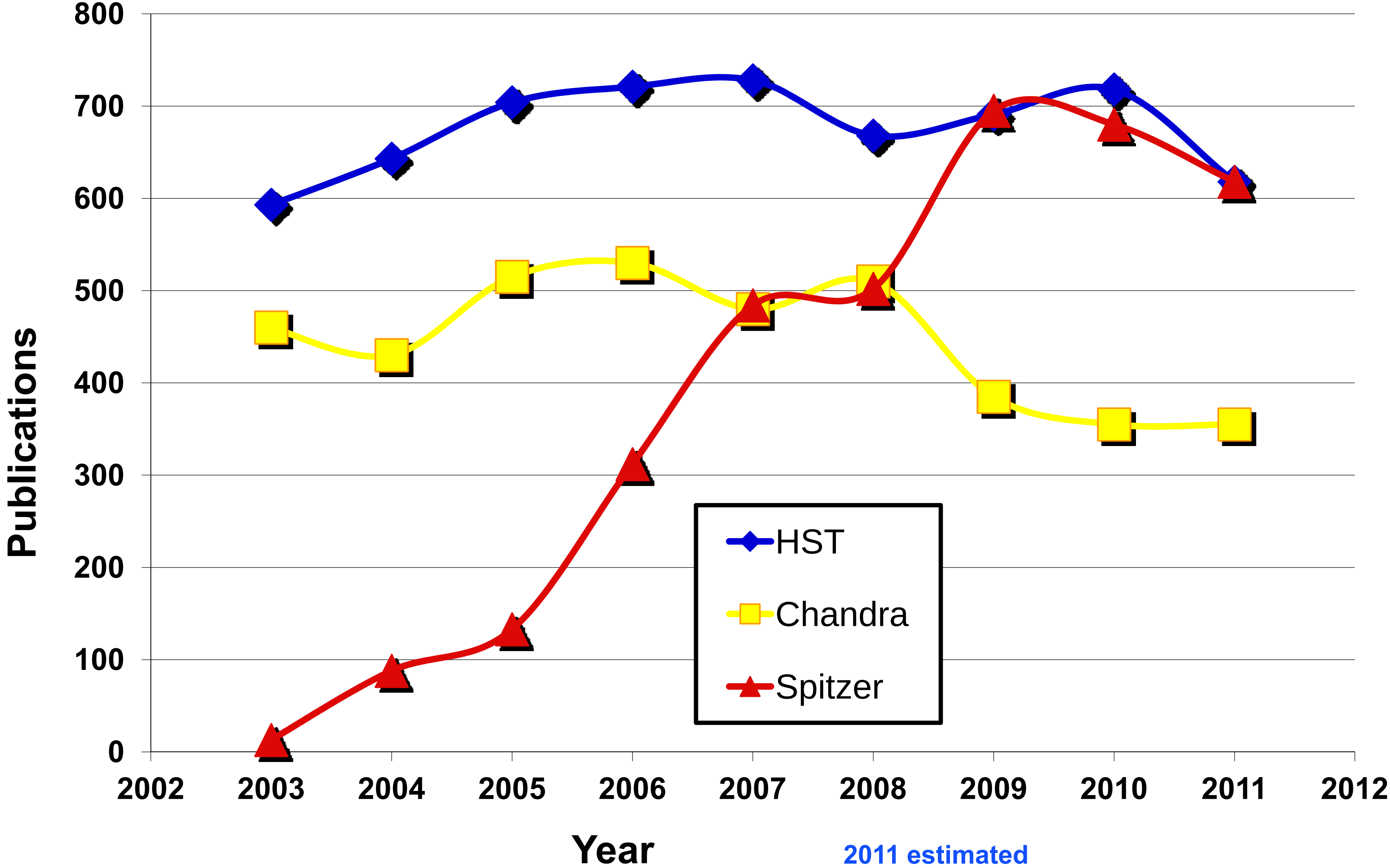
Spitzer Project - Mean FTEs / year			
	1 Dec 2003 Start of Science Operations	FY06 Cryogen Operations	FY10 Warm Operations
Project Offices	15.8	9.0	4.3
Mission Operations	64.7	35.4	18.0
SSC + Outreach	112.5	95.8	32.0
Total	193.0	140.2	54.3
% FTEs compared to Start of Science Ops			
		73%	28%

Mission Summary

	Cryogen Operations	Warm Operations
Observing Programs Supported Annually	250	60
Mean Hours of Science Executed Annually	7250	7800
Operating Budget ($million)	37	18
User Community Budget ($million)	35	4
Total Budget ($million)	72	22
Mean Operating Cost/Hour	$5,100	$2,800

- Can operate through at least 2016 ($ permitting)

Science Productivity



2011 estimated

Fin

- Innovative design + robust engineering
  + dedicated staff → outstanding science
- Mission funded to operate through late 2012
- Proposing to NASA to continue operations

Warm Spitzer science addresses the most compelling questions of current day astrophysics, ranging from probing the atmospheric structure of exoplanets to determining when the first galaxies formed.

- Acknowledge Deborah Levine, Bill Latter, Rick Ebert, Jeff Jacobson, Dario Fadda, Mark Lacy, Harry Teplitz