Scheduling Spitzer – The SIRPASS Story

David S. Mittman
Jet Propulsion Laboratory, California Institute of Technology

Robert Hawkins
Space Telescope Science Institute

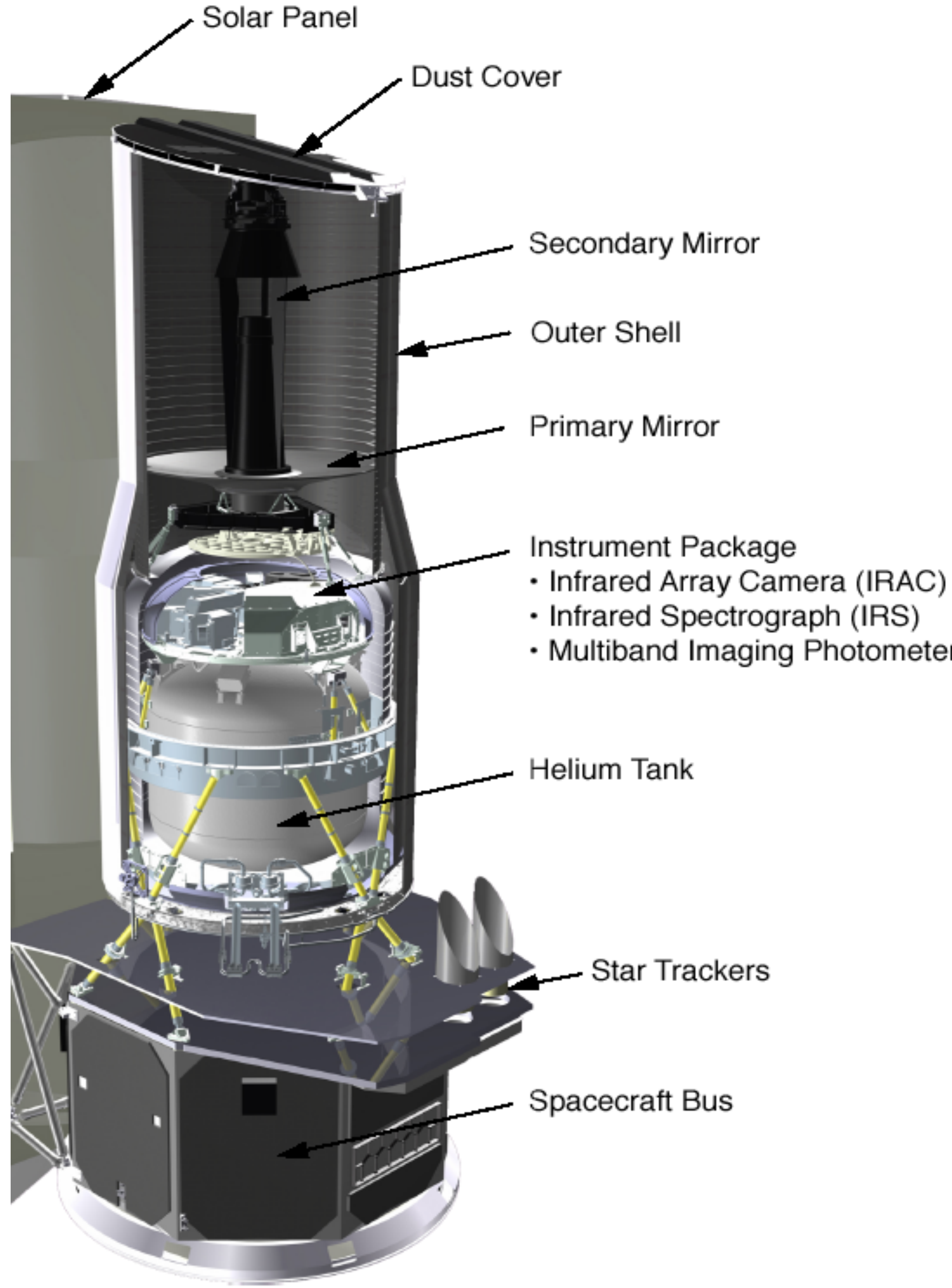
Agenda

- Introduction
  - Spitzer Space Telescope
  - Normal Operations and Interfaces
  - Observatory Planning and Scheduling Team
- SIRPASS
  - Plan-IT II Core
  - Spike
  - Adaptation
- Experiences, Lessons Learned and Conclusions

Introduction

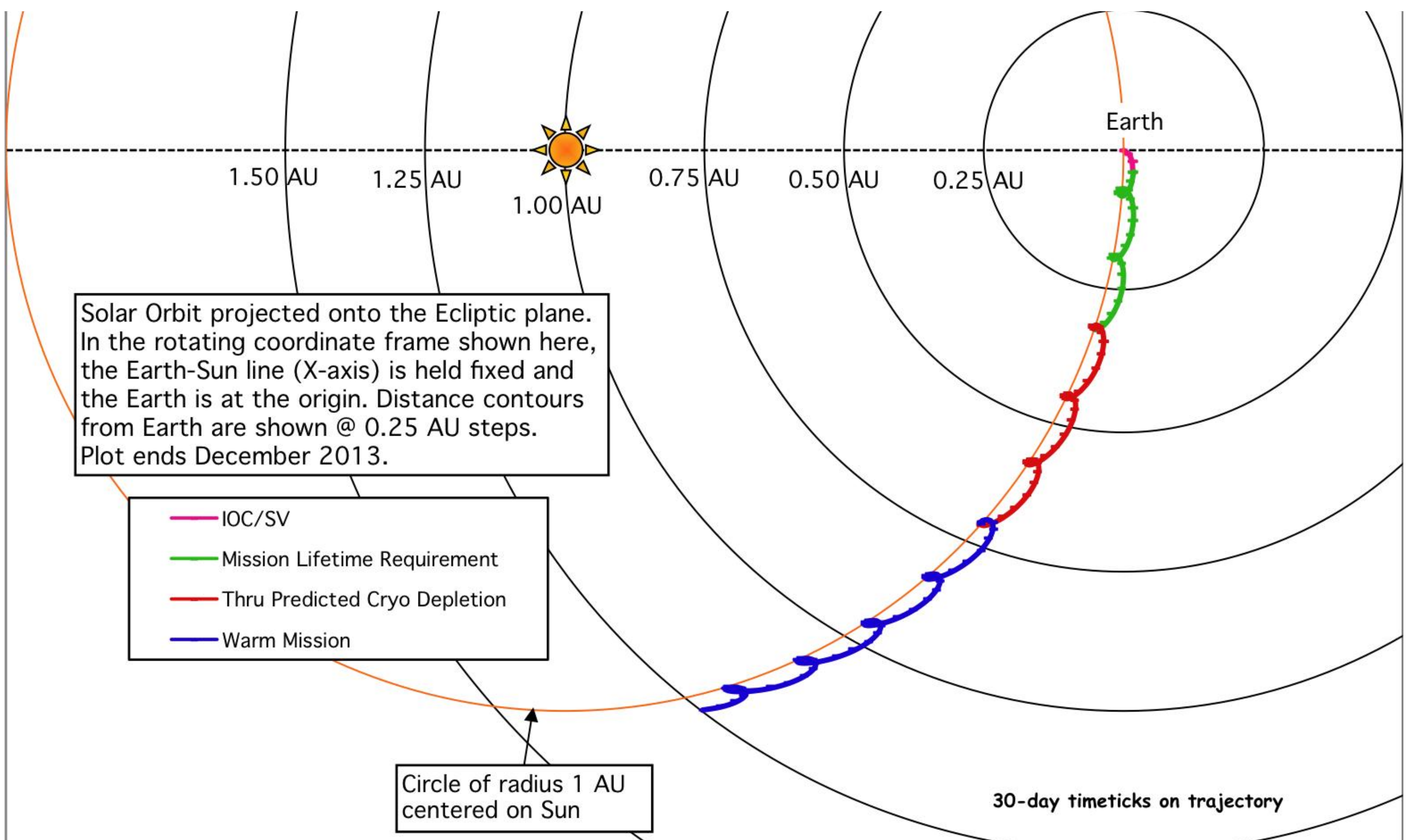
Spitzer Space Telescope

- Shuttle Infrared Telescope Facility (SIRTF) @ Ames, 1977
- High Earth Orbit, 1988
- Earth-Trailing, Warm Launch @ JPL, 1993
- SIRTF Phase C/D, 1997
- Launch and Renaming, 2003
- Depletion of Cryogen, 2009

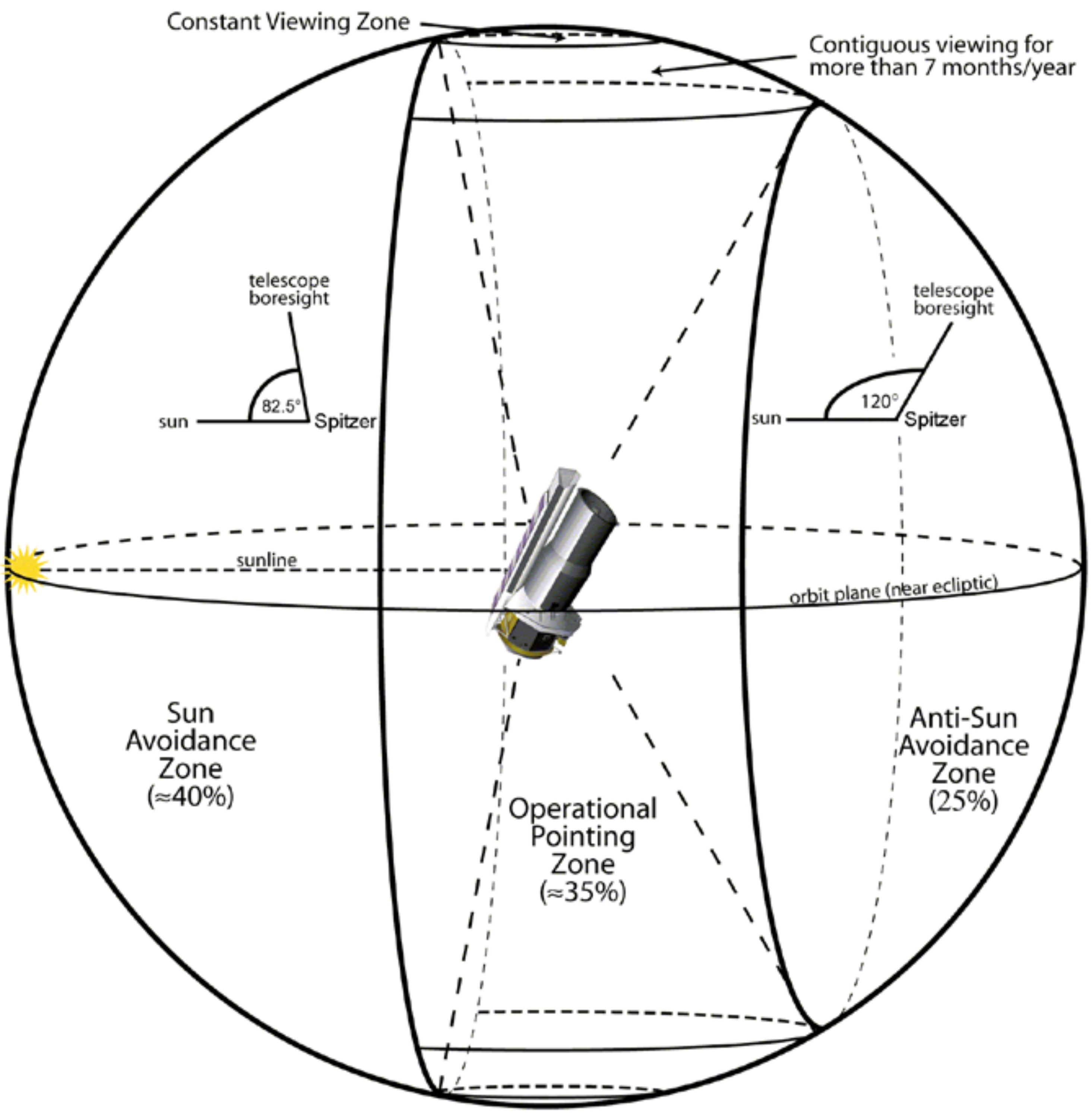


Spitzer Solar Orbit

- Spitzer is in an earth-trailing solar orbit, slowly drifting away from Earth at rate of approximately 0.64 AU every five years.
- Although this orbit was chosen primarily for thermal and launch mass considerations, it also vastly improves the simplicity and efficiency of operations.

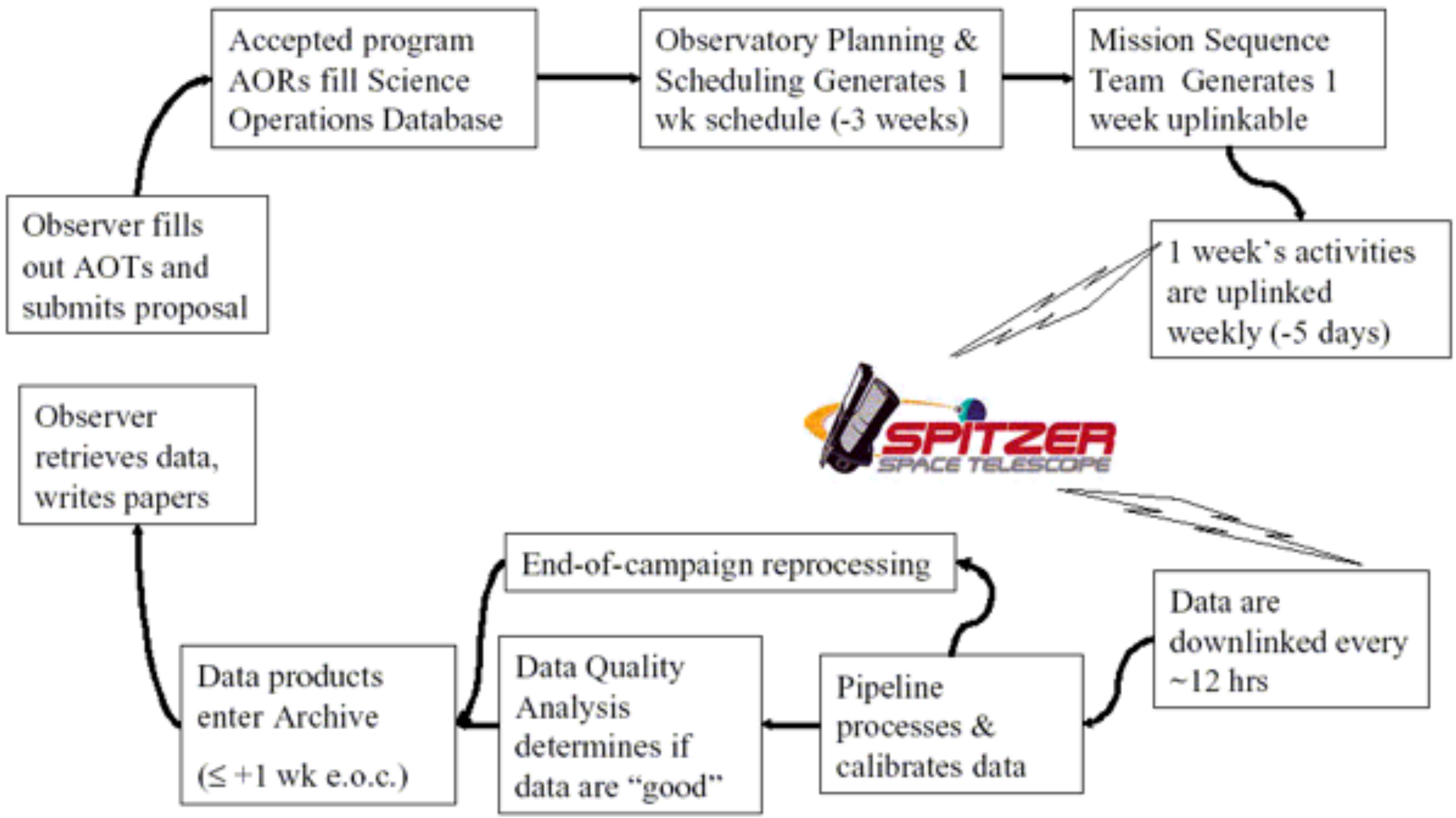


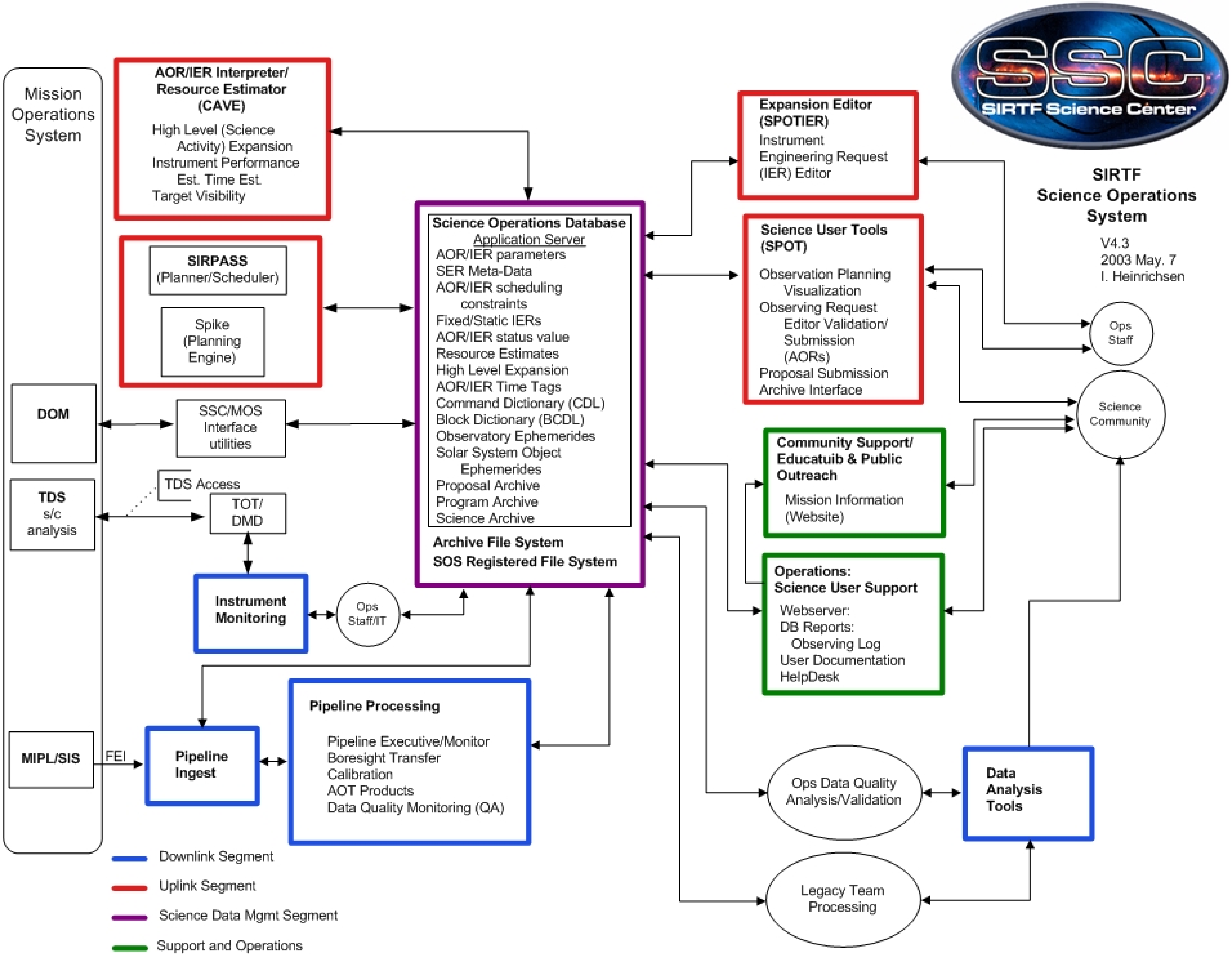
Operational Pointing Zone

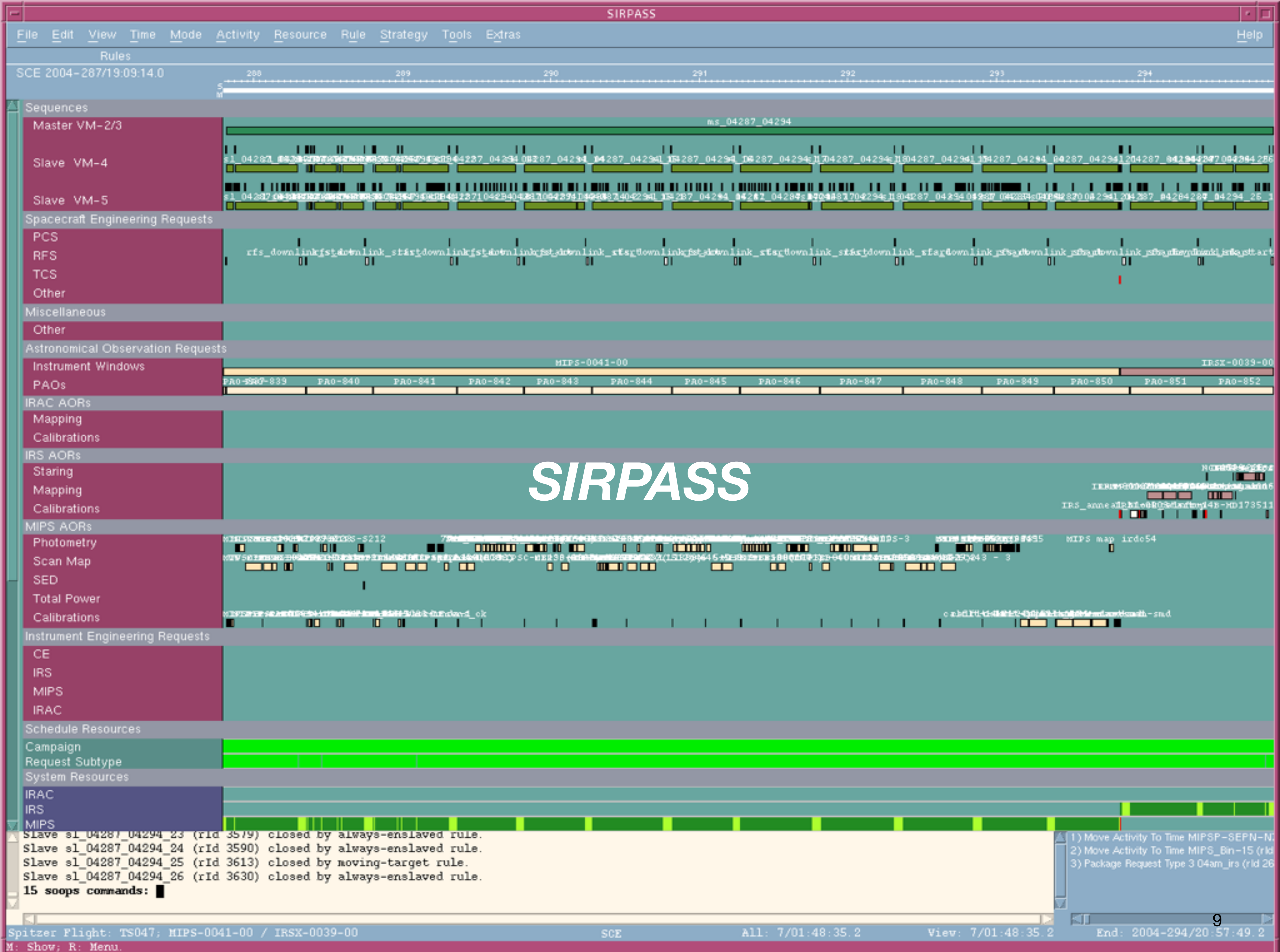


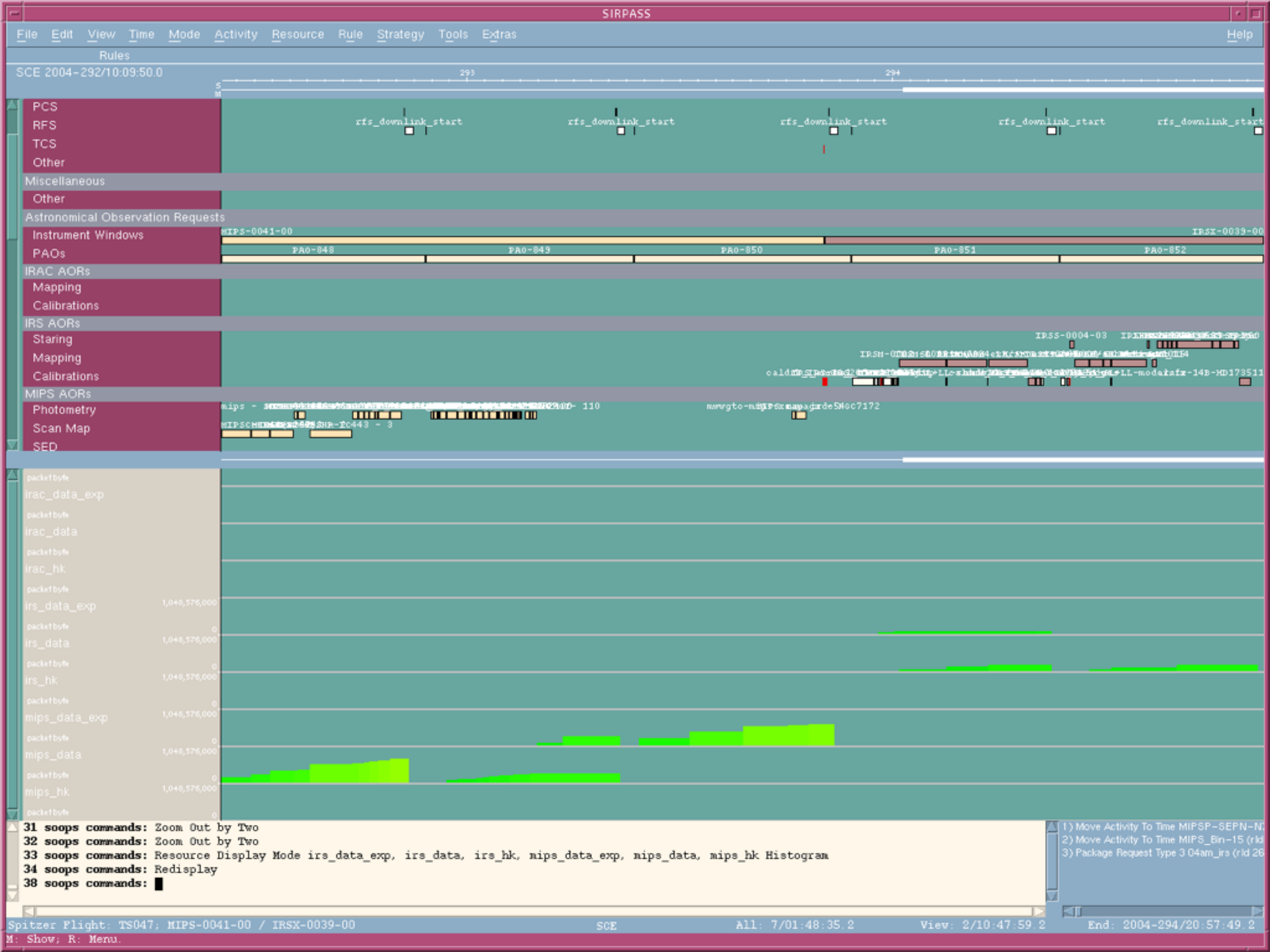
- As a cryogenically cooled spacecraft, Spitzer is constrained to keep its solar arrays and sun shield pointed toward the Sun by restricting its ability to pitch and roll.
- As a result of these pointing restrictions, Spitzer can only observe targets within a narrow annulus that rotates about the sun once per year, but ends up covers all inertial targets for at least 40 days each year.

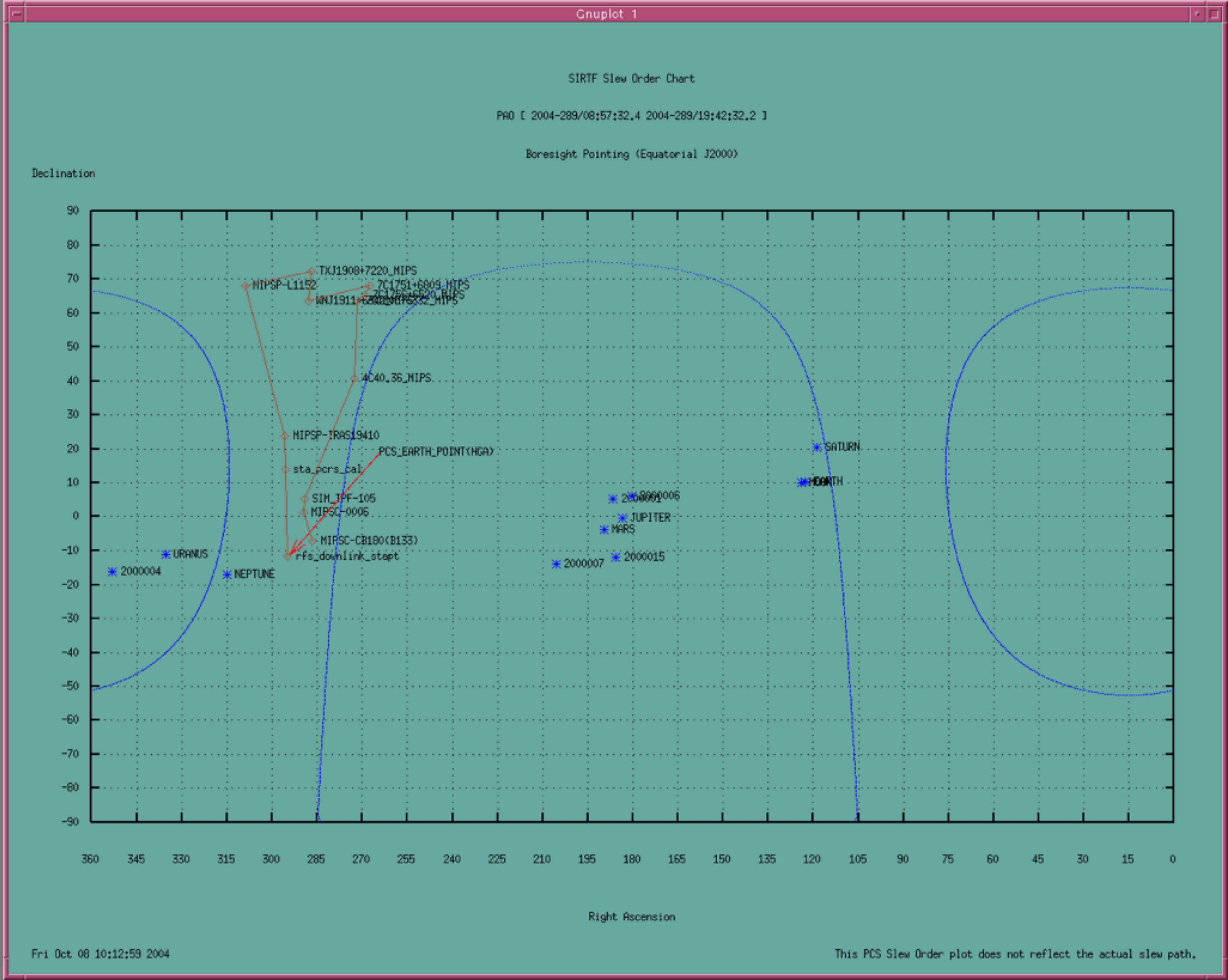
The Life Cycle of a Spitzer Observation




SIRTF Science Center
SIRTF
Science Operations
System
V4.3
2003 May. 7
I. Heinrichsen
Mission
Operations
System
AOR/IER Interpreter/
Resource Estimator
(CAVE)
High Level (Science
Activity) Expansion
Instrument Performance
Est. Time Est.
Target Visibility
SIRPASS
(Planner/Scheduler)
Spike
(Planning
Engine)
DOM
SSC/MOS
Interface
utilities
TDS Access
TDS
s/c
analysis
TOT/
DMD
Instrument
Monitoring
Ops
Staff/IT
Science Operations Database
Application Server
AOR/IER parameters
SER Meta-Data
AOR/IER scheduling
constraints
Fixed/Static IERs
AOR/IER status value
Resource Estimates
High Level Expansion
AOR/IER Time Tags
Command Dictionary (CDL)
Block Dictionary (BCDL)
Observatory Ephemerides
Solar System Object
Ephemerides
Proposal Archive
Program Archive
Science Archive
Archive File System
SOS Registered File System
Expansion Editor
(SPOTIER)
Instrument
Engineering Request
(IER) Editor
Science User Tools
(SPOT)
Observation Planning
Visualization
Observing Request
Editor Validation/
Submission
(AORs)
Proposal Submission
Archive Interface
Ops
Staff
Science
Community
Community Support/
Educatuib & Public
Outreach
Mission Information
(Website)
Operations:
Science User Support
Webserver:
DB Reports:
Observing Log
User Documentation
HelpDesk
MIPL/SIS
FEI
Pipeline
Ingest
Pipeline Processing
Pipeline Executive/Monitor
Boresight Transfer
Calibration
AOT Products
Data Quality Monitoring (QA)
Ops Data Quality
Analysis/Validation
Data
Analysis
Tools
Legacy Team
Processing
Downlink Segment
Uplink Segment
Science Data Mgmt Segment
Support and Operations


SIRPASS
File Edit View Time Mode Activity Resource Rule Strategy Tools Extras Help
Rules
SCE 2004-287/19:09:14.0
Sequences
Master VM-2/3
ms_04287_04294
Slave VM-4
Slave VM-5
Spacecraft Engineering Requests
PCS
RFS
TCS
Other
Miscellaneous
Other
Astronomical Observation Requests
Instrument Windows
MIPS-0041-00
IRSX-0039-00
PAOs
PAO-840
PAO-841
PAO-842
PAO-843
PAO-844
PAO-845
PAO-846
PAO-847
PAO-848
PAO-849
PAO-850
PAO-851
PAO-852
IRAC AORs
Mapping
Calibrations
IRS AORs
Staring
Mapping
Calibrations
SIRPASS
MIPS AORs
Photometry
Scan Map
SED
Total Power
Calibrations
MIPS map irdc54
Instrument Engineering Requests
CE
IRS
MIPS
IRAC
Schedule Resources
Campaign
Request Subtype
System Resources
IRAC
IRS
MIPS
Slave sl_04287_04294_24 (rId 3590) closed by always-enslaved rule.
Slave sl_04287_04294_25 (rId 3613) closed by moving-target rule.
Slave sl_04287_04294_26 (rId 3630) closed by always-enslaved rule.
15 soops commands:
1) Move Activity To Time MIPSP-SEPN-N
2) Move Activity To Time MIPS_Bin-15 (rId
3) Package Request Type 3 04am_irs (rId 26
Spitzer Flight: TS047; MIPS-0041-00 / IRSX-0039-00
SCE
All: 7/01:48:35.2
View: 7/01:48:35.2
End: 2004-294/20:57:49.2
M: Show; R: Menu.


SIRPASS
File Edit View Time Mode Activity Resource Rule Strategy Tools Extras Help
Rules
SCE 2004-292/10:09:50.0
293
294
PCS
RFS
TCS
Other
rfs_downlink_start
Miscellaneous
Other
Astronomical Observation Requests
Instrument Windows
PAOs
MIPS-0041-00
IRSX-0039-00
PAO-848
PAO-849
PAO-850
PAO-851
PAO-852
IRAC AORs
Mapping
Calibrations
IRS AORs
Staring
Mapping
Calibrations
IRSS-0004-03
MIPS AORs
Photometry
Scan Map
SED
irac_data_exp
irac_data
irac_hk
irs_data_exp
irs_data
irs_hk
mips_data_exp
mips_data
mips_hk
packetbyte
1,048,576,000
0
31 soops commands: Zoom Out by Two
32 soops commands: Zoom Out by Two
33 soops commands: Resource Display Mode irs_data_exp, irs_data, irs_hk, mips_data_exp, mips_data, mips_hk Histogram
34 soops commands: Redisplay
38 soops commands:
1) Move Activity To Time MIPSP-SEPN-N
2) Move Activity To Time MIPS_Bin-15 (rld
3) Package Request Type 3 04am_irs (rld 26
Spitzer Flight: TS047; MIPS-0041-00 / IRSX-0039-00
SCE
All: 7/01:48:35.2
View: 2/10:47:59.2
End: 2004-294/20:57:49.2
M: Show; R: Menu.



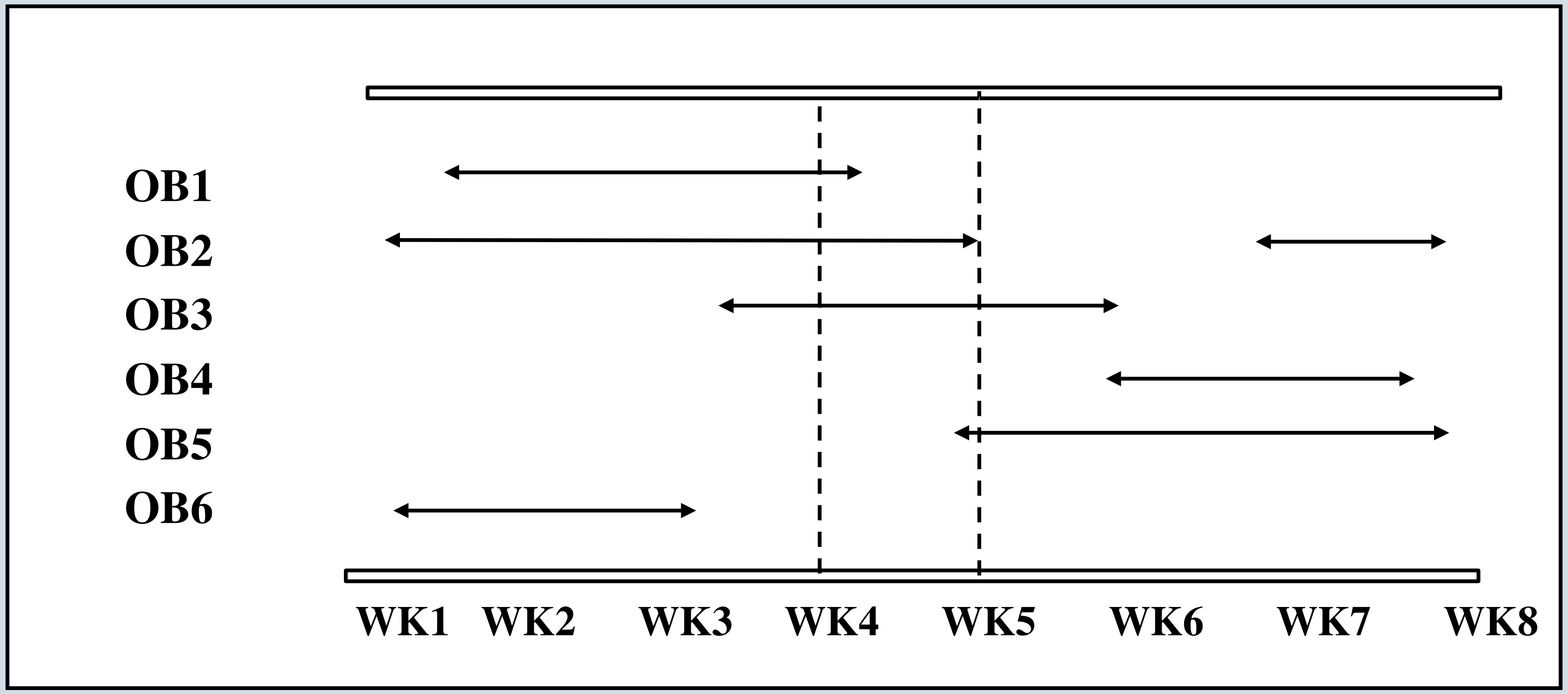
Gnuplot 1
SIRTF Slew Order Chart
PAO [2004-289/08:57:32.4 2004-289/19:42:32.2]
Boresight Pointing (Equatorial J2000)
Declination
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
TXJ1908+7220_MIPS
MIPSP-L1152
7C1751+6809_MIPS
4C40.36_MIPS
MIPSP-IRAS19410
PCS_EARTH_POINT(HGA)
sta_pcrs_cal
SIM_TPF-105
MIPSC-0006
MIPSC-CB180(B133)
rfs_downlink_start
2000004
URANUS
NEPTUNE
SATURN
JUPITER
MARS
2000007
2000015
360
345
330
315
300
285
270
255
240
225
210
195
180
165
150
135
120
105
90
75
60
45
30
15
0
Right Ascension
Fri Oct 08 10:12:59 2004
This PCS Slew Order plot does not reflect the actual slew path.

Spike

- General toolkit for constraint-based planning and scheduling developed for the Hubble Space Telescope by STScI which has evolved over the years with HST and other mission deployments into a robust software package that is easily adaptable for new missions, including:

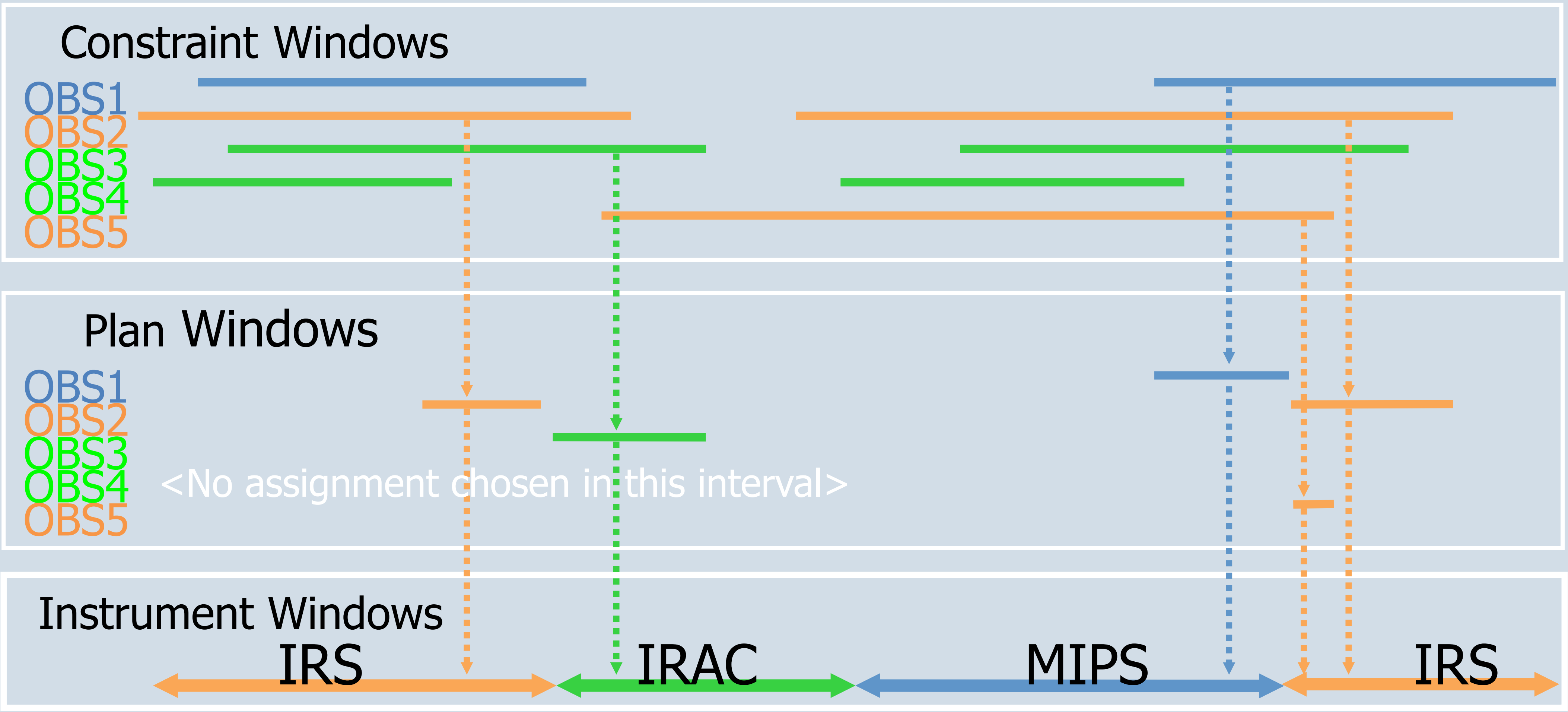
HST	Chandra
JWST	Spitzer
FUSE	Subaru
ESO-VLT	OpTIIX

- Plan Window Concept: Rather than schedule observations to weekly bins, assign a least-commitment subset of constraint windows, ensuring better plan stability.
- Short-term scheduler picks from observations(1,2,3,5) whose windows overlap the current week(4):

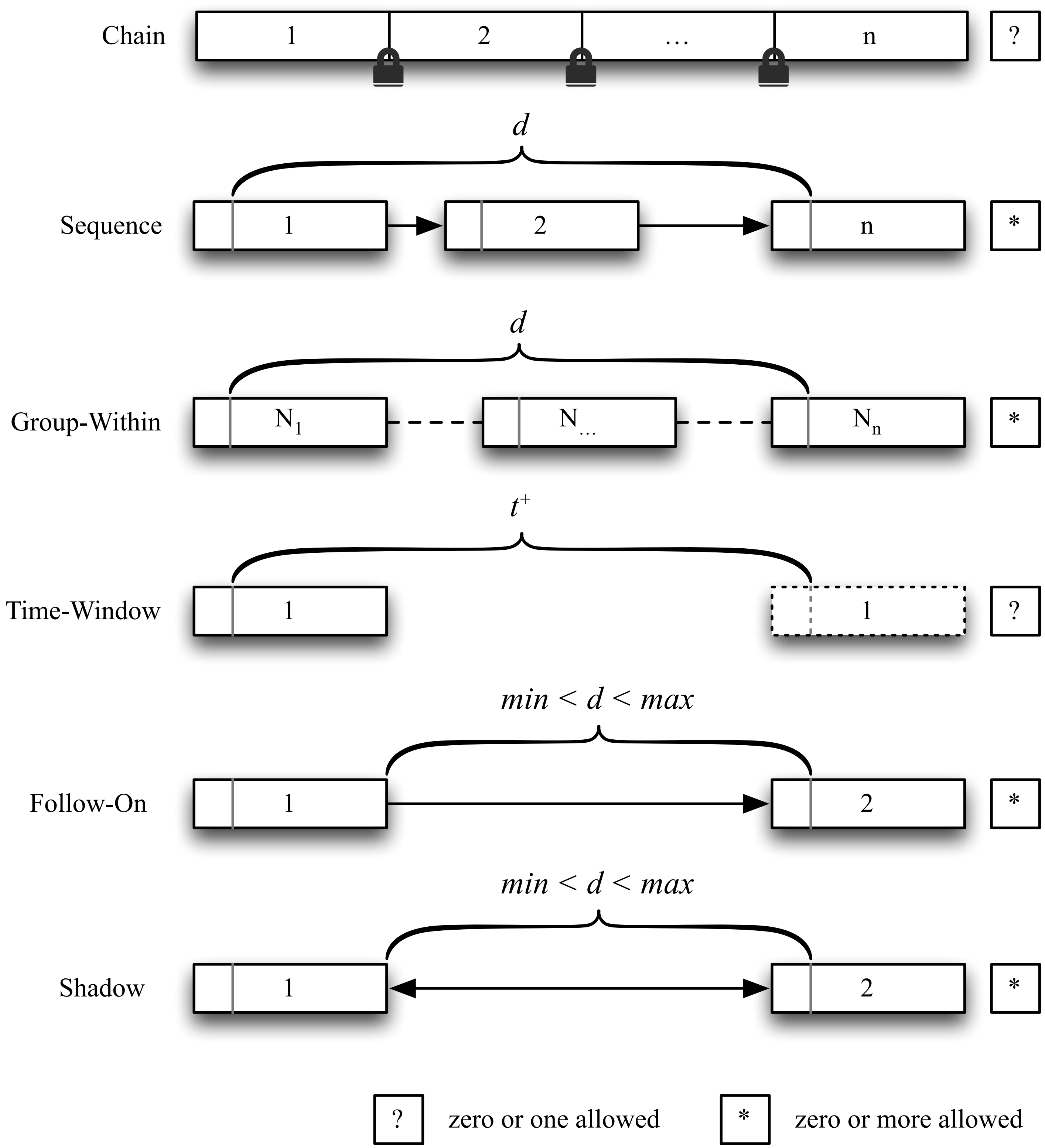


Spitzer Spike

- Constraint-Windows > Instrument Windows > Plan Windows
- Added “Instrument Window” concept to construct Baseline Instrument Campaign:
  - Non-overlapping, adjoining time intervals
  - Intervals are from one day to weeks long
  - Need to minimize instrument transitions to preserve cryogen and propellant
  - Preferred instrument ordering to optimize cryogen and propellant

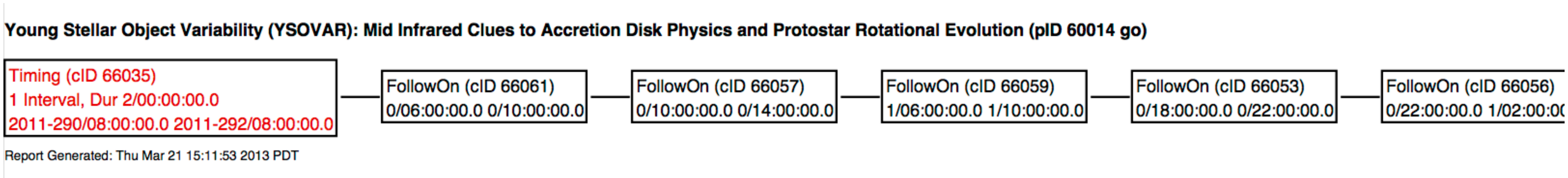


Constraints



- Chain, an ordered, non-interruptible group
- Sequence, an ordered, interruptible group
- Group-within, an unordered group with start/stop duration limit
- Time-window, a series of execution time intervals
- Follow-on, an ordered pair with stop/start duration limit
- Shadow, a target point duplicating Follow-on

Tree-Walking Algorithm



- Hundreds of programs with hundreds of requests per program
- Each request may participate in either "zero or one," or "zero or more" of each type of constraint.
    - A request may participate in zero or one Chain and Time-Window constraints, and in zero or more Sequence, Group-Within, Follow-On, or Shadow constraints.
    - A request cannot participate in both a Sequence and a Chain constraint; if this occurs, the Chain constraint is ignored.
- Too complex to depict request network; depict constraint network instead.

Greedy Scheduling

Term	C	F	S	Description
0	-6,000	1	0.06	Constant Term
1	1	f	1	Target Slew (Prolog) Cost (secs)
2	1	f	0	Request Schedule-Window Duration Remaining in Seconds
3	1	f	0	Request Schedule-Window End Offset in Seconds
4	1	f	0	Program Type
5	1	f	0	Highly Constrained Request
6	1	f	1	Chain
7	1	f	1	Request Schedule Window Ends Within

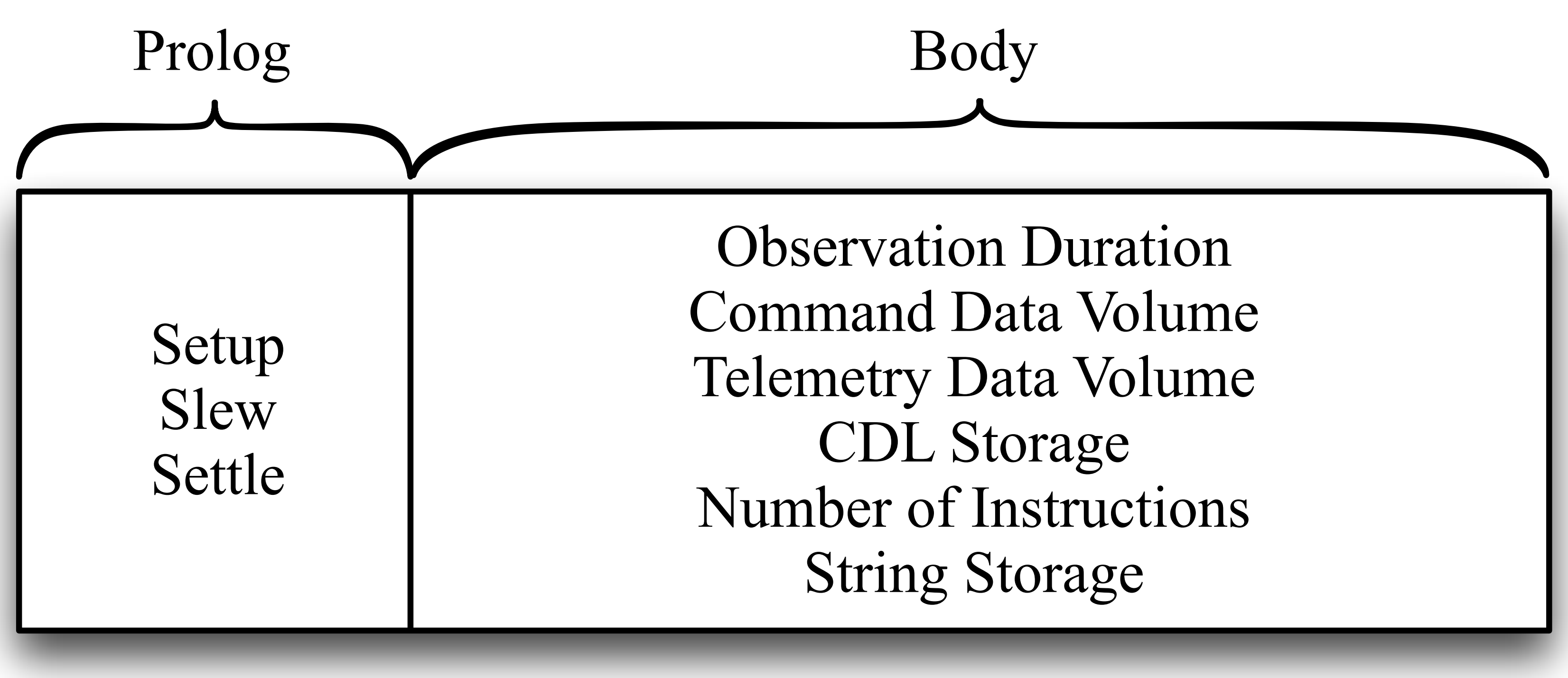
- Adapted from HST (Samson 1998)
- Coefficients can be per-Request, set by OPST
- Scaling values control the value of each term independent of Coefficients
- Scales have changed over the mission

Greedy Scheduling, cont.

- Scheduling Activities on the timeline is done manually, with rules, or automatically
- Greedy scheduling is an automatic approach
- Scheduling adheres to constraints, interface indicates violations
- Can Greedy schedule an entire week, a single PAO or any arbitrary time interval

Request Estimates

- AIRE calculates body resource estimates that are used later in the scheduling domain
- Targeting is the responsibility of the slew model, used by both SIRPASS and AIRE.
- Request expansion to library calls is the responsibility of AIRE; this keeps SIRPASS highly interactive without bogging it down expanding activities to individual commands.
- Request expansion to spacecraft commands and the modeling of those commands is the responsibility of SEQGEN, a computationally demanding process



Request Packaging

Next Request is…

Previous Request is…		SER: Pseudo SER	SER: True SER	IER: Power Transition	IER: Other	AOR: Moving Target	AOR: Fixed Target
SER	Pseudo SER	✓*	✓*	✓*	✓*	✓*	✓*
SER	True SER	✓*	✓	✗	✗	✗	✗
IER	Power Transition	✓*	✗	✓†	✗	✗	✗
IER	Other	✓*	✗	✗	✓	✗	✓
AOR	Moving Target	✓*	✗	✗	✓	✗	✓
AOR	Fixed Target	✓*	✗	✗	✓	✗	✓

*Only if one or both of the Pseudo-SERs are always enslaved.

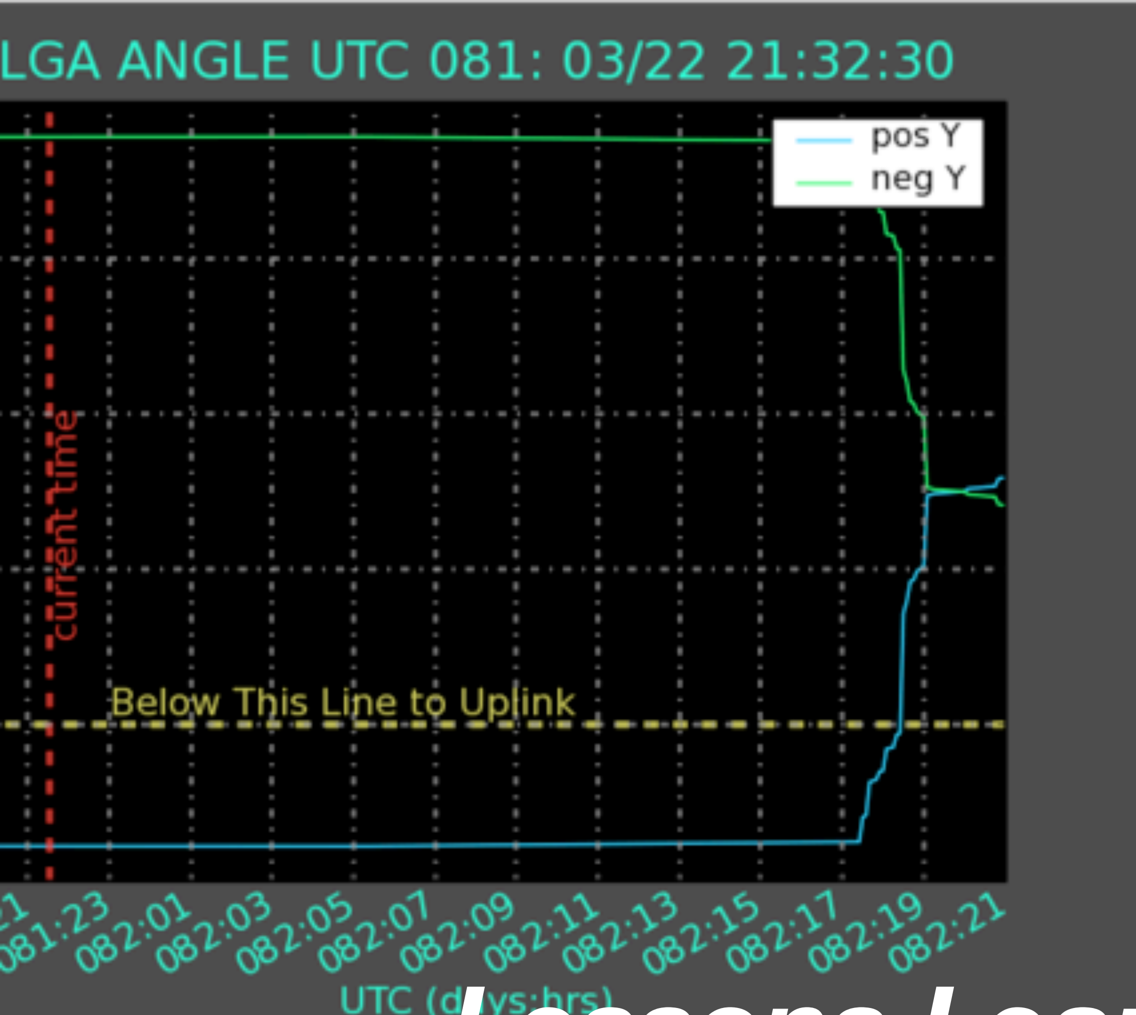
†Only if both Power Transition IERs are for the same instrument.

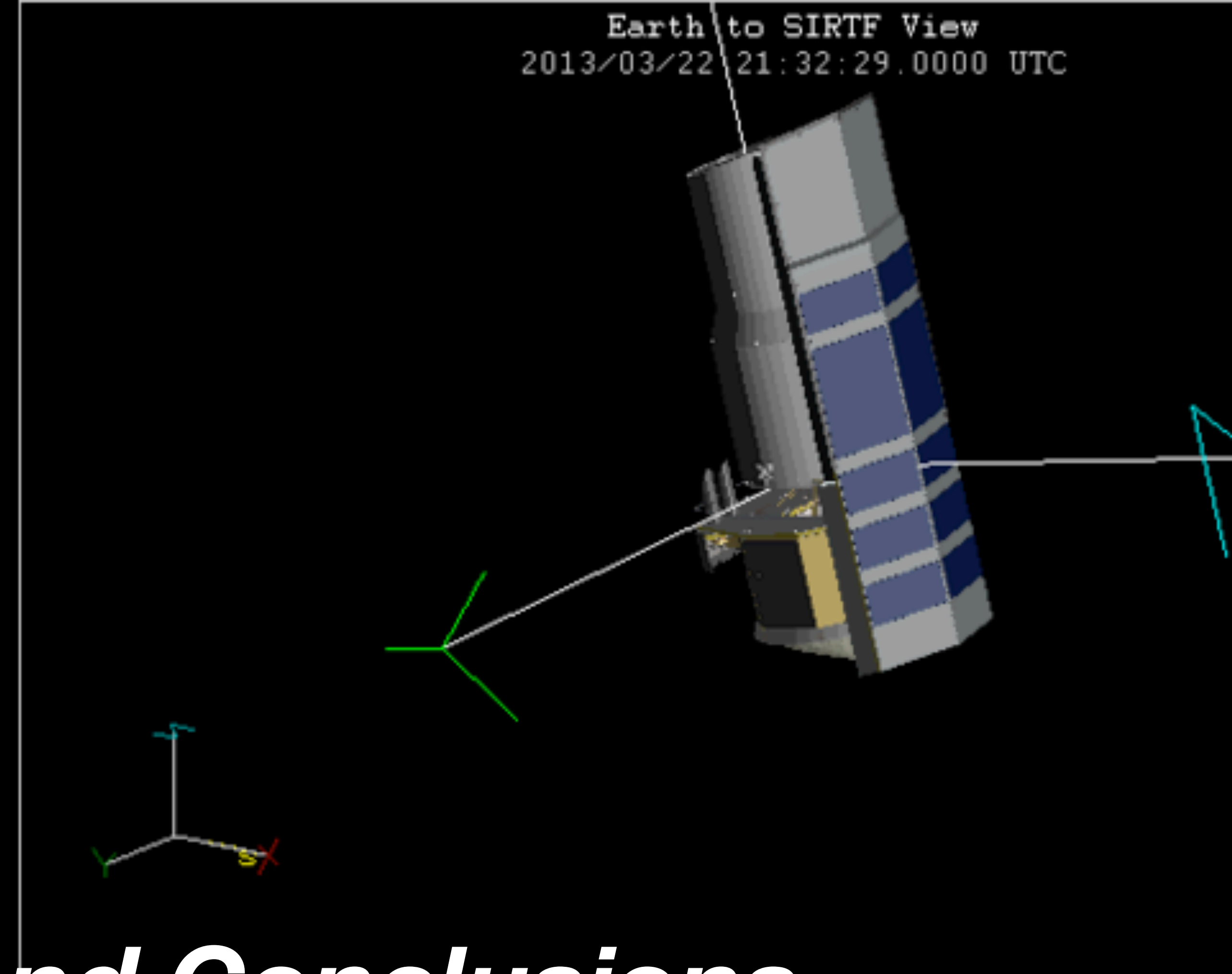
APIDs and DPTs

APID		Description
11	ENG_NOMINAL_MODE_RT	S/C health and status while in nominal mode (real-time)
12	ENG_NOMINAL_MODE	S/C health and status while in nominal mode
13	PCS	Data required for pointing reconstruction (selected data from PCS, Thermal, etc.)
20	IRAC_DATA_EXP	IRAC instrument data (from AORs and IERs) specified by the ground to be sent first (e.g. calibration data)
21	IRAC_DATA	Unexpedited IRAC data (from AORs and IERs)
22	IRAC_MEM	IRAC normal engineering telemetry

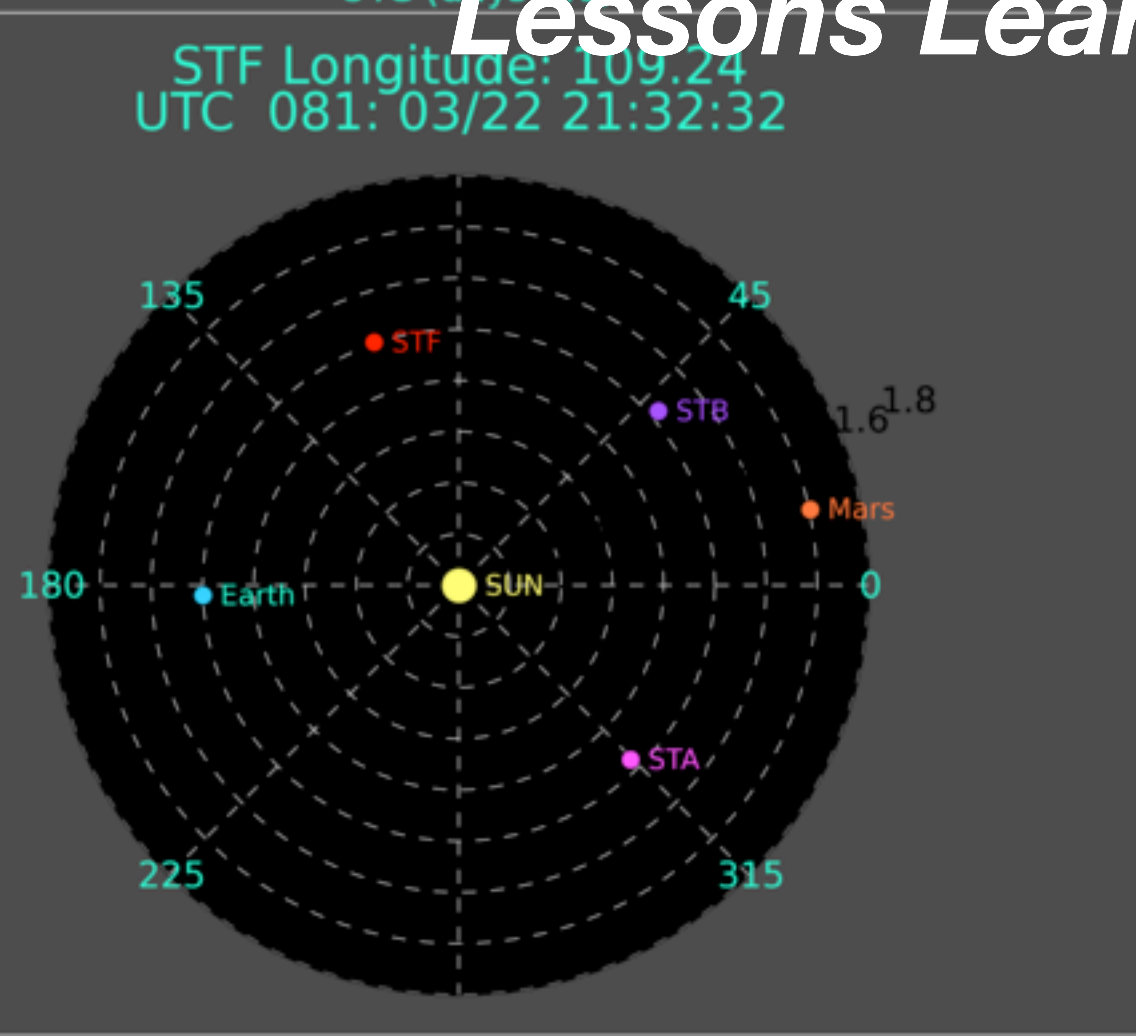
<table>
<tr><th>Level</th><th colspan="60">APIDs</th></tr>
<tr><td>0</td><td colspan="60">retransmit</td></tr>
<tr><td>1</td><td colspan="20">rt_nom_fast</td><td colspan="20">rt_nom_med</td><td colspan="20">rt_nom_slow</td></tr>
<tr><td>2</td><td colspan="4">evr</td><td colspan="4">…</td><td colspan="4">…</td><td colspan="4">irac</td><td colspan="4">…</td><td colspan="4">…</td><td colspan="4">…</td><td colspan="4">irs</td><td colspan="4">…</td><td colspan="4">…</td><td colspan="4">…</td><td colspan="4">…</td><td colspan="4">ce</td><td colspan="4">…</td><td colspan="4">…</td></tr>
<tr><td>3</td><td colspan="30">sc_spare_3</td><td colspan="30">sc_spare_4</td></tr>
<tr><td>4</td><td colspan="15">pt_recon</td><td colspan="15">irac_data_exp</td><td colspan="15">irs_data_exp</td><td colspan="15">mips_data_exp</td></tr>
<tr><td>5</td><td colspan="20">irac_data</td><td colspan="20">irs_data</td><td colspan="20">mips_data</td></tr>
</table>

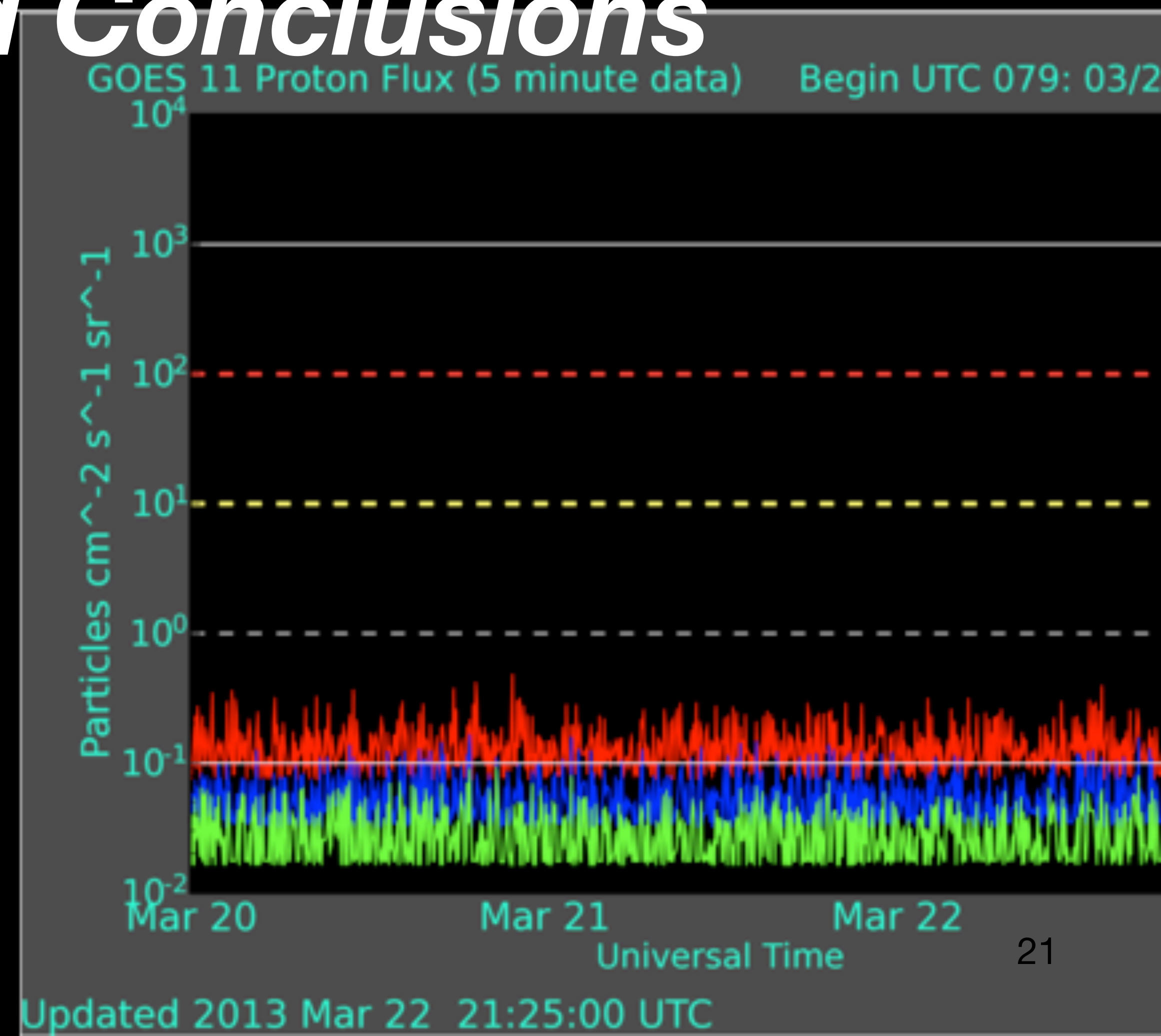
- Queues for spacecraft-generated data
- Priorities for downlinking data
- Simple specification
- Moderately complex system-level effects
- Highly-complex activity-level effects
- “When does” vs “How do I” questions
- Contrast MPF, STF, MSL





Lessons Learned and Conclusions





SIRPASS

- Question Assumptions; Perform Design Trades
  - Limits help put a bounding box around a design, until they don't
  - Spend extra now (within reason) to save later
- Plan for Longevity, Reduced Staff and Budget
  - I&T/V&V are your friends, until they move away
  - Plan for better, faster, cheaper ways of doing business
- Manage Complexity
  - You **will** over-engineer your systems
  - Capability will remain unused
  - Abstract your interfaces away from over-engineered systems
- Create partnerships; modularize algorithms; create portable APIs and build system support

Spitzer Spike

- Original Plan
  - Nail down the estimated ~10% absolute time observations
  - Fit instrument window campaigns to result
  - Generate plan windows for remaining observations by intersecting constraint and instrument windows
- Reality
  - 1% absolute time observations = poor instrument campaigns using original model
  - Needed input campaigns, more flexible initial campaign layout in Spike
- So…Campaign scheduling concept was useful…BUT
- Design for Change!
  - Observatory mission software designs are typically laid out years in advance, then retro-fitted to match in-orbit reality
  - Incorporate modular design, manual overrides, extension capabilities in initial software design

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- The authors additionally wish to thank the members of the Spitzer Observatory Planning and Scheduling Team for their support in the creation and use of SIRPASS.