Mission Planning Updates

S. W. Randall

with thanks to many others (Pat Slane, Jan Vrtilek, Josh Wing, Daniel Castro, Ewan O'Sullivan, Cecilia Garraffo, Tara Dowd, Ed McClain, Matt Dahmer, John Scott…..)

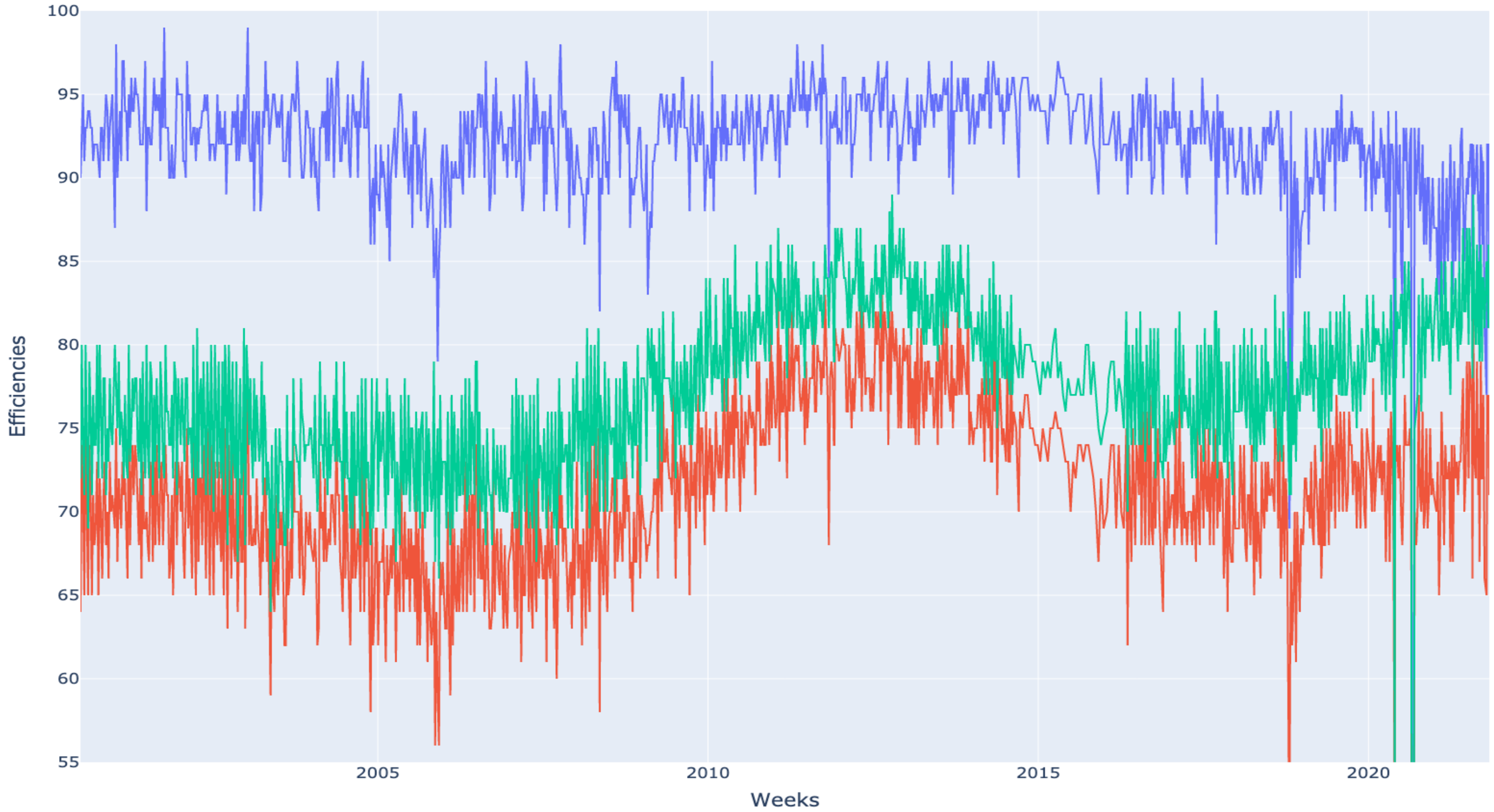
Overall Context for Mission Planning

Goal:
Maximizing the science return of the mission in the presence of constraints:

Observation constraints, e.g.,
- coordination
- time windows
- continuity of observations
- monitoring series and observation grouping
- roll constraints
- phase constraints

Engineering constraints, e.g.,
- *thermal constraints*
- *star field constraints*
- momentum management
- Sun, Moon, Earth, bright X-ray source avoidance

Mission Efficiency History



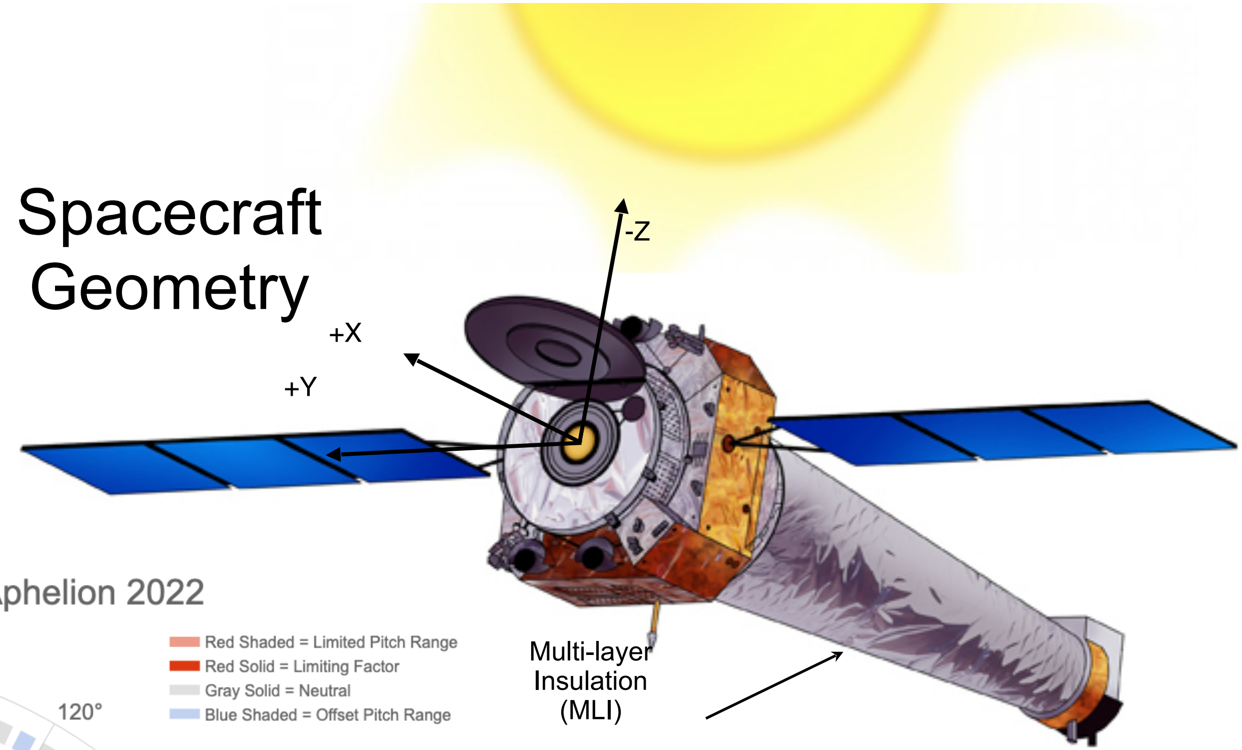
Science time/above radzone time.

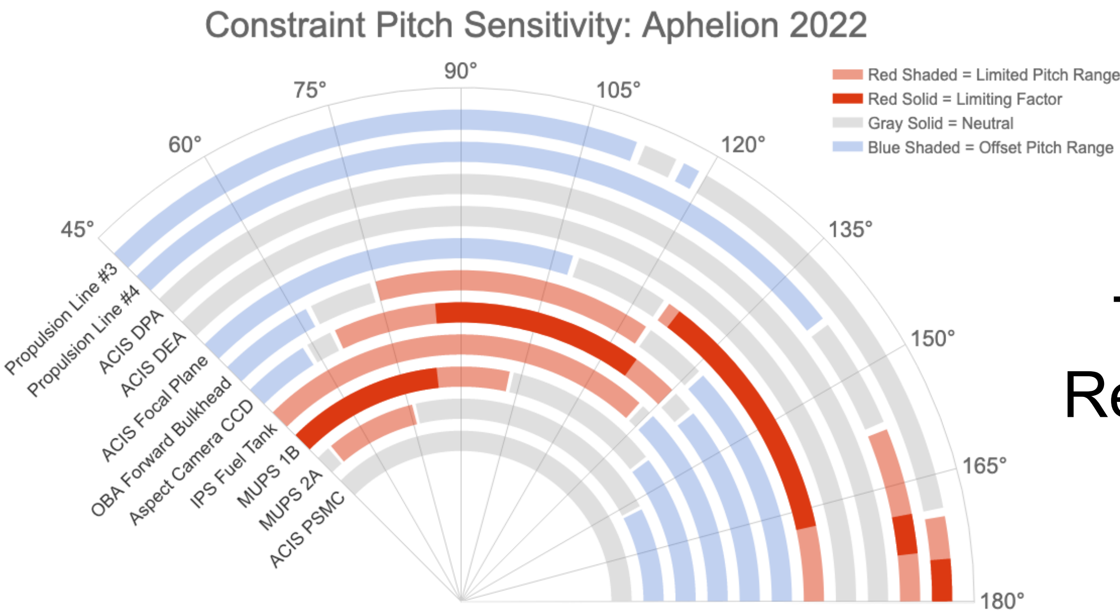
Above radzone time/wallclock time.

Science time/wallclock time.

Chandra Thermal Restrictions

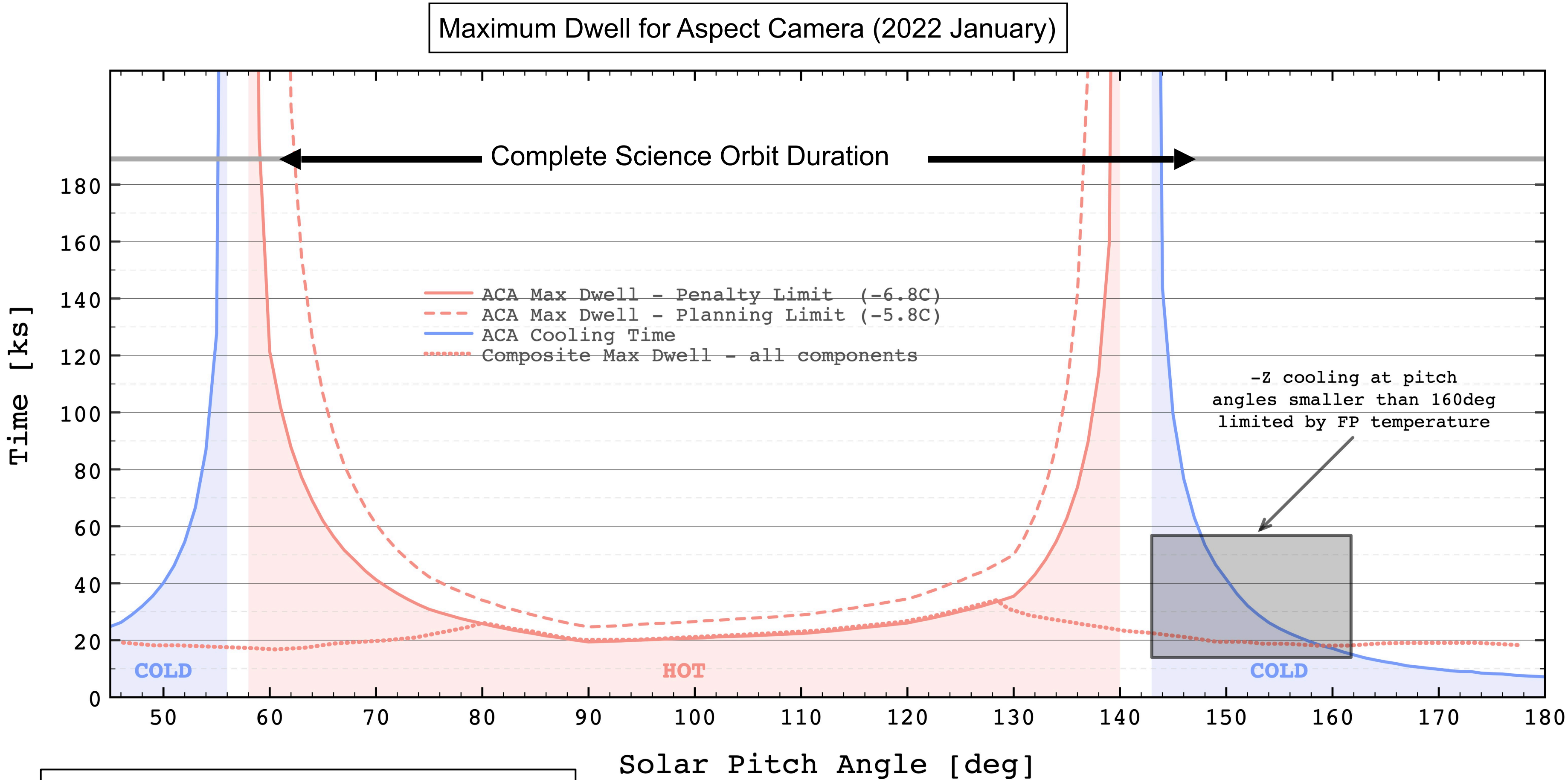
Spacecraft Geometry





Thermal Restrictions

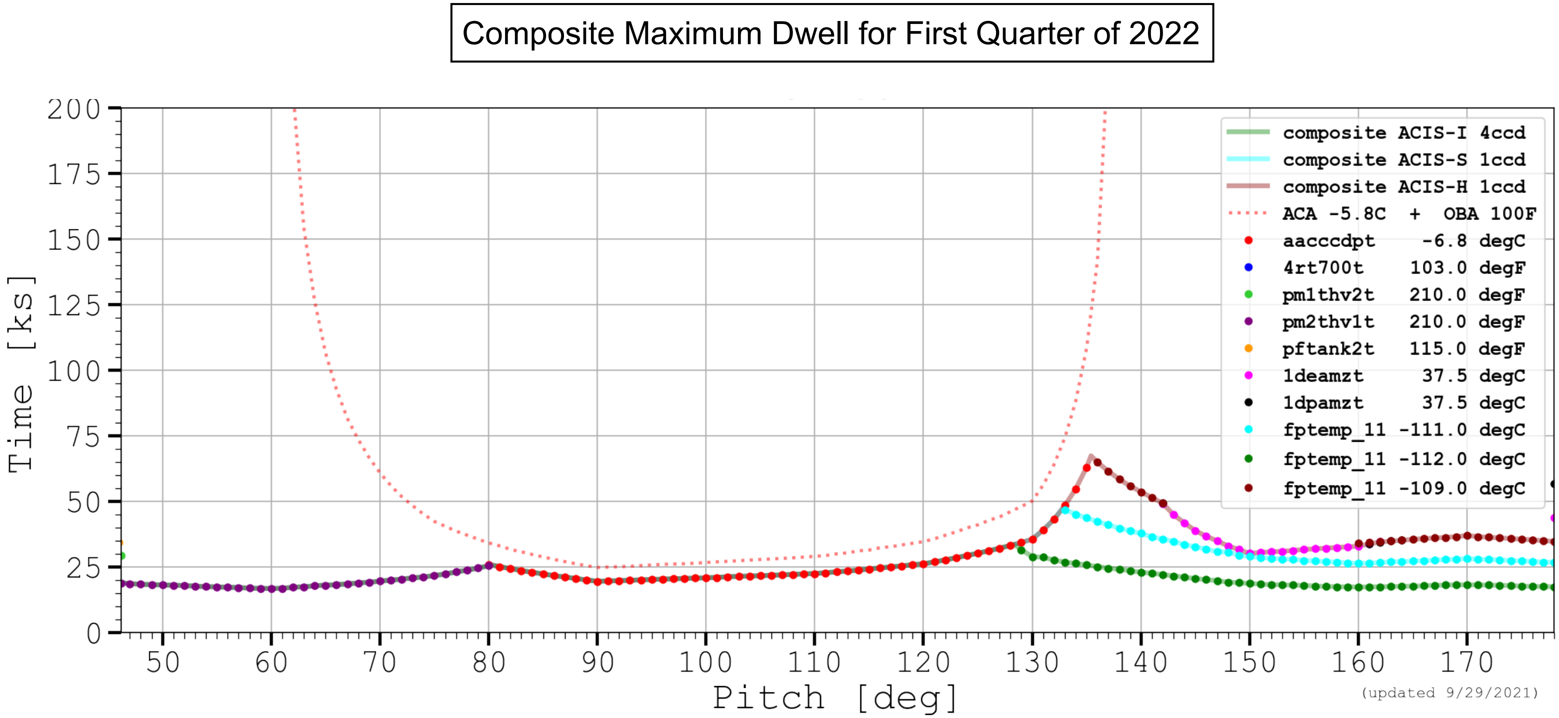
Thermal Balance: A Summary



Red: maximum exposure before exceeding temperature limit (dotted is **composite** for all components).

Blue: minimum cooling time required to return to state from which another max dwell possible

Thermal Balance: A Summary

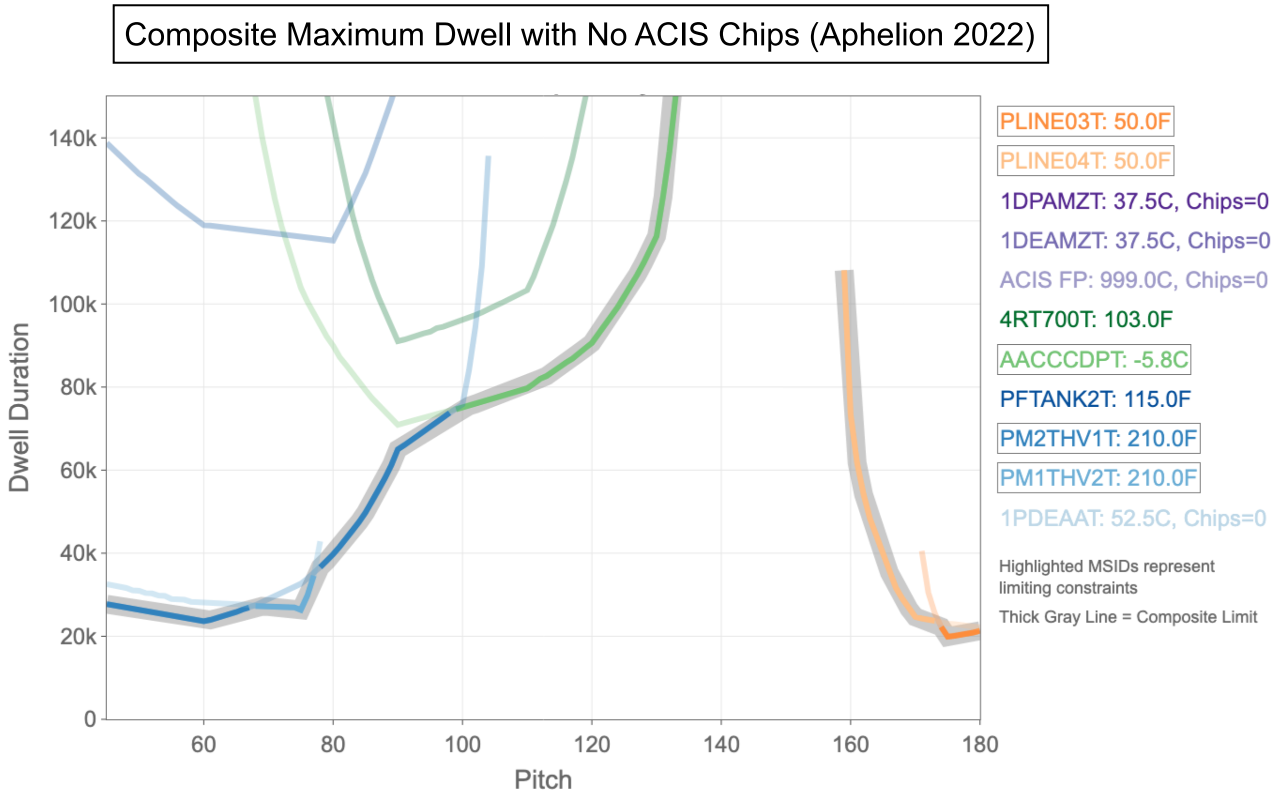


- Composite max dwell time plot is now relatively flat, since the ACA is now less disfavored as compared with other components (but still need high pitch angles!)

- We have been working hard to stay ahead of rising temperatures with component limit increases, but that can only go so far….

- The MUPS thruster valve limits are not expected to increase significantly, which places tight and *permanent* limits on the maximum dwell time below 80 deg pitch

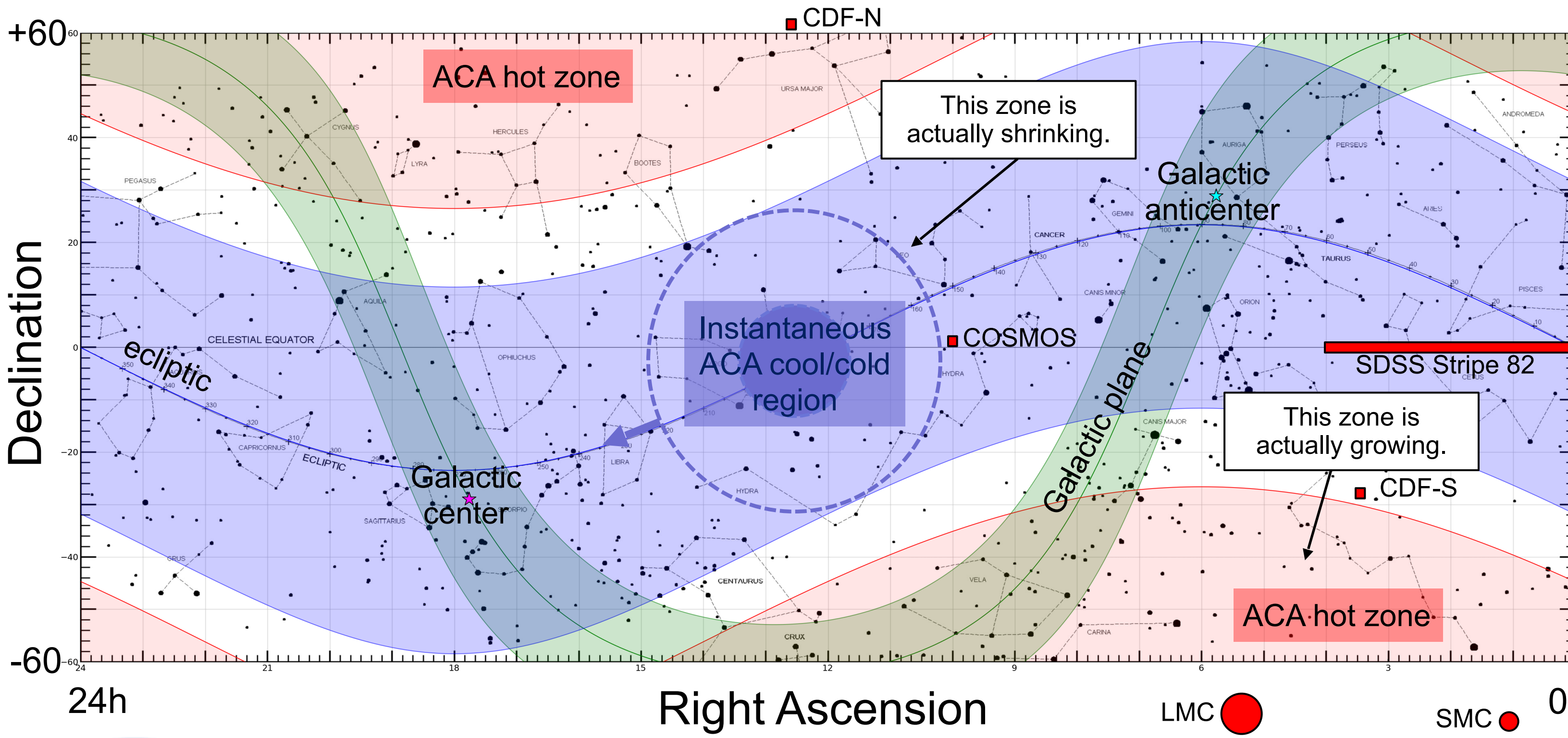
Future Thermal Needs

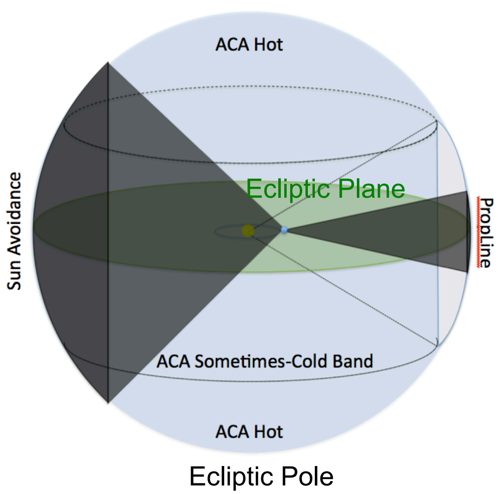


- Most limiting components cool at high pitch angles, except ACIS.
- Therefore, turning off all ACIS chips greatly increases the maximum dwell at high pitch angles (limited at the highest pitch angles by the propulsion lines)

- This means that HRC observations are especially useful for cooling most thermal components (and useful at other pitch angles for cooling ACIS).
- We expect HRC observations to become more and more useful as the global average temperature of the spacecraft continues to rise.

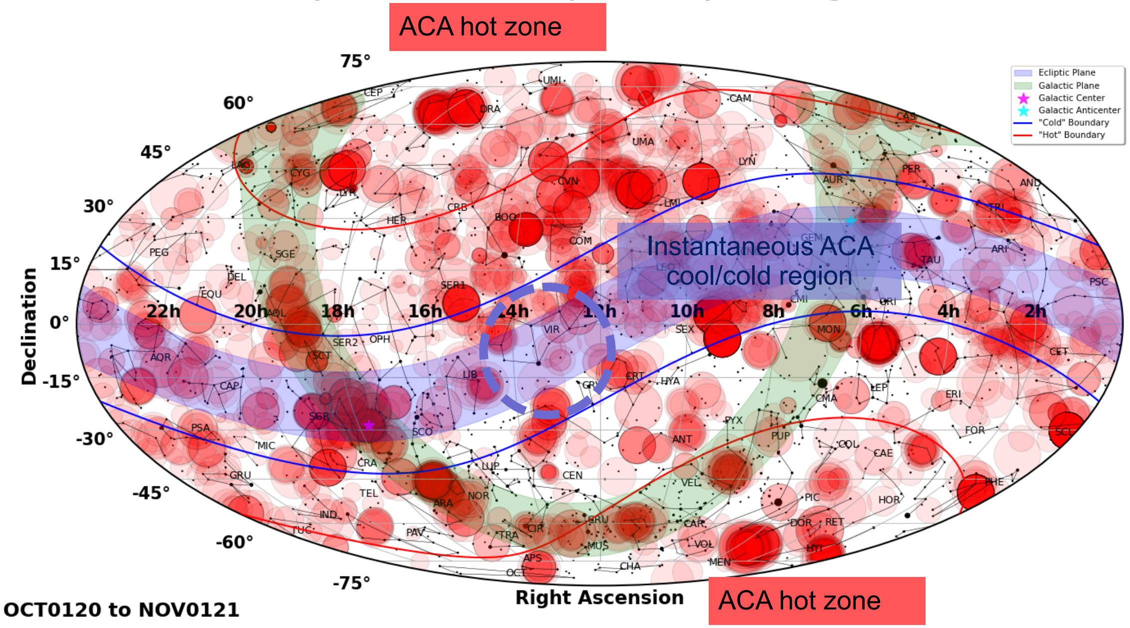
Constraints: Sky View



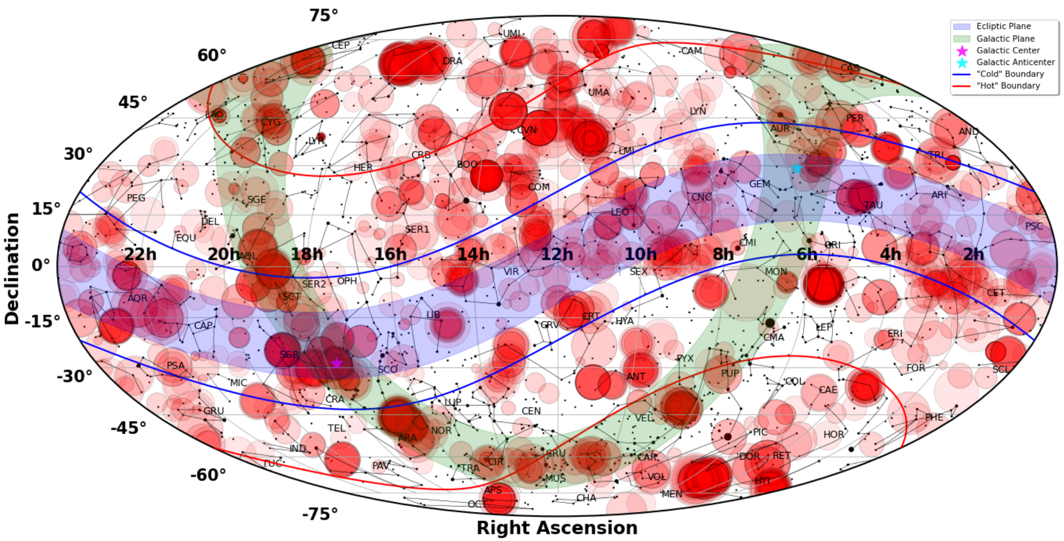


- Sometimes-cool/cold ACA (-Z) region covers large sky area.
  - Many well-known fields can provide some cooling; others always heat the ACA.
  - The cool regions are shrinking and the hot ones are growing.
  - In cycle 22 &23, observing time assigned by peer review at high ecliptic latitudes ($|\beta|>55°$) is limited to 2.5Ms.

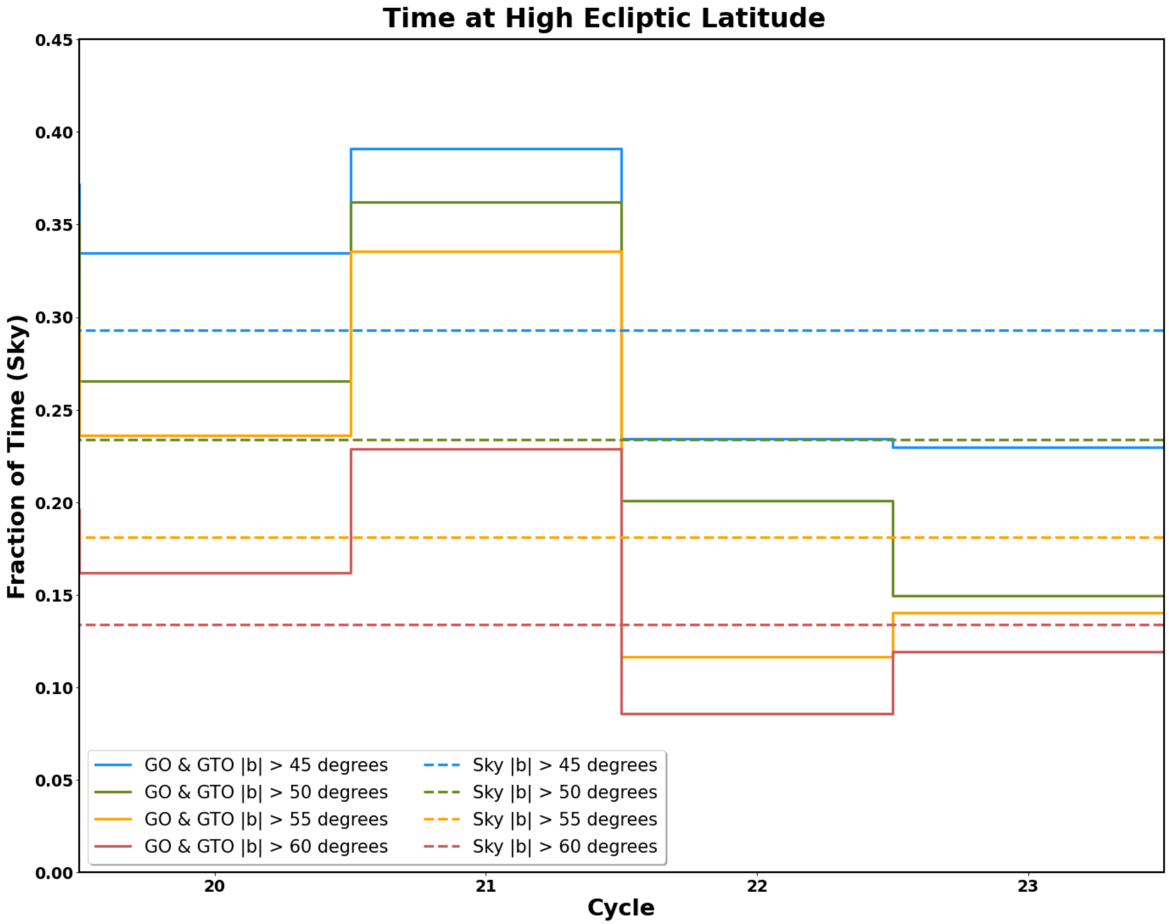
Exposure Scaled Scatterplot of All Cycle 23 Targets



Exposure Scaled Scatterplot of All Targets Observed OCT0120 to NOV0121



Target Distribution: Cycle 22



- For several cycles, the CXC has been limiting high ecliptic latitude time in large programs only.
- This has not proven adequate: target times at high β have ended up *above* their proportionate share of sky area.
- Consequences include very long (~6 month) LTS development times and programs that extend far into subsequent cycles.
- Cycle 22+, with high-latitude time limited for *all* targets, finally achieves high-latitude target times somewhat below their proportionate sky area.

- Due to “catching up” with time from earlier cycles and the decreased relative importance of ACA heating, we ***may*** be able to increase the time limit on high latitude targets, <u>but low-latitude time is still crucial for cooling</u>.

Sample of Significant Planning Efforts

<u>Completed in Cycle 22:</u>

- Sgr A* - 250 ks, including
  - GRAVITY campaign (7 x 21.6 ks)
  - EHT campaign (4 x 25 ks)

- Transient propeller-phase neutron star ULXs, 750 ks:
  - Three targets, each a tight monitor series of 10 observations with roughly one every 1 -1.5 months
  - Two of the targets go into sunblock, which *very* tightly constrains where these can be placed

- RXJ1131-1231, 180 ks
  - 6x30 observations, tight coordination constraint with XMM essentially fixes them in the LTS

- PKS 0023-26, 170 ks
  - No workable ACA solution, at any temperature. Required special consultation with the ACA team.
  - Ultimately led to very tight observing windows with extra ACA cooling.

- PSR B2224+65, 400 ks; SNR 0519-69.0, 400 ks; PSZG311, 442 ks
  - Always bad pitch

- A2319, 560 ks
  - Always bad pitch.

Sample of Significant Planning Efforts

<u>Coming Up in Cycle 23:</u>

- Galactic Center mosaic, 1.7 Msec; CMZ Molecular Cloud, 900 ks
  - Leftover from Cycle 22
  - 2.6 Msec all in the same part of the sky (same “good” and “bad” pitch windows)

- Sgr A* - 100 ks
  - Tightly coordinated with the EHT

- Abell 2029, 440 ks:
  - Bad star field will required lower ACA temperatures
  - Star field limits observations to a ~4 week window

- LMC N132D, 100 ks
  - 4x25 ks, constrained to be uninterrupted, roughly at the ecliptic pole where the maximum dwell time time is also about 25 ks.

- PSZ2G358.98-67.26, 4.9 ks; 2MASX J15114125+0518089, 60 ks
  - Very difficult to observe star fields, with maximum ACA temperatures of -13.9C and -10.8 C, respectively (ACA planning limit is -5.8 C, more on this later)

- B1152+199, 70 ks
  - 7x10 ks, monitor series with a monthly cadence that also has a difficult star field.

Tool/Process/Limit Updates

Staffing issues

- Pat Slane and Jan Vrtilek left SOTMP in late 2020 (and we thank them for many years of invaluable service!)

- Combined with other staffing issues, SOTMP was down to 1 scientist and 3 technical assistants (out of a nominal 4/4) for ~2 months in early 2021, and 2 scientists and 3 technical assistants for a longer stretch.

- After a thorough search, we welcomed Cecilia Garraffo and Ewan O'Sullivan to the team as SOTMP scientists in April, and Iris Wang as a technical assistant in June.

Tool/Process/Limit Updates

Operational Events

- HRC anomaly in ate August, 2020.
- Recovery from the LETG anomaly in late August 2021 required suspending **<u>all</u>** grating observations for an extended period. This was particularly poorly timed for the LTS, and had a massive impact on scheduling.
- In October Chandra briefly shut down due an IU reset anomaly, and we also experienced out first radiation-related shutdown in several years.
- Switching back to a single IRU (after using two IRUs following the gyro anomaly) and turning off the unneeded “bus 6/zone 50” heater resulted in “gaining back” about 1 year of heating for the ACA.

Tool/Process/Limit Updates

LTS Building

- With all of the thermal and other planning constraints, laying out the LTS is a computationally challenging task, which used to take ~6 months to do by hand.

- Over the past several years, we have been working with a software development team at StSCI to develop auto-scheduling software to help build the LTS. We have continued to debug and update this code, which is now approaching a more-or-less “final state”.

- An important new capability, as of late Summer 2021, is a “repair mode”, which takes an existing schedule and repairs (i.e., thermally balance and fill) unacceptable weeks. This new feature will likely be particularly helpful for unanticipated operational events (e.g., the recent LETG anomaly).

Tool/Process/Limit Updates

LTS Building

- For Cycle 23, we adopted a fixed start date for the next LTS, in mid-November, before which we did not schedule any Cycle 23 observations. This required using several hundred ksec of CCT time to balance the end of the Cycle 22 schedule

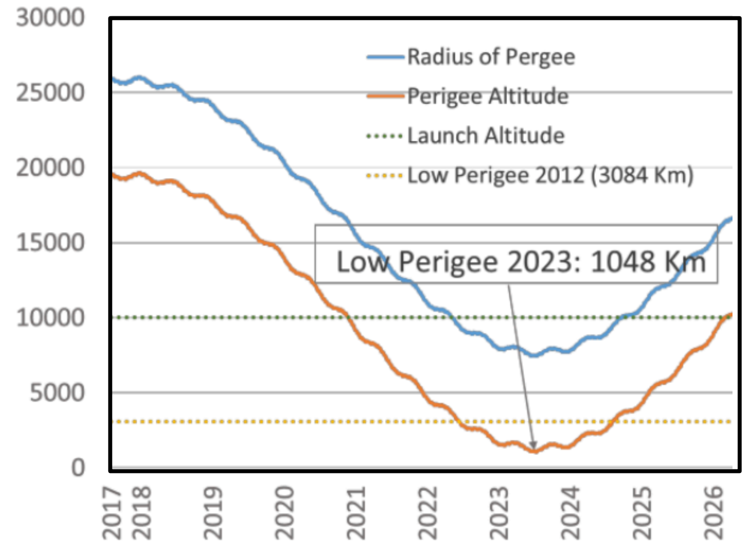
- This approach greatly simplified the LTS building process, and when combined with software improvement to the auto-scheduler, allowed us to build a reasonably complete and balanced LTS for a full year for the first time in several years.

- Manual “polishing” of this schedule is ongoing.

Tool/Process/Limit Updates

Momentum Management

- Chandra will reach its lowest perigee altitude in 2023, requiring an increase in the use of the thrusters to unload momentum.
- Degradation of the A-side thrusters was observed after ~700 “warm starts”, resulting in a switch to the B-side thrusters in 2013.
- Goal is to budget warm starts to stay under this limit of 700 through low-perigee.
- Developed software to estimate the momentum accumulation per axis for any observation, allowing the “momentum balance” to be calculated for every week.
- Momentum is now balanced week by week when laying out the LTS, as is done for thermal.



Tool/Process/Limit Updates

Other Updates

- New Constraints:
  - Working with the Director's Office and the Data Systems team to implement two new constraints for Cycle 24:
    - A "split constraint", which limits how long we can take to complete a program once we start it.
    - A "unique phase" constraint, which, for phase constrained observations, requires splits done in different phase windows to cover unique parts of the phase.

- Science Orbit Calibration Measurements:
  - We are no longer able to get sufficient calibration source measurements from radiation zones alone. SOTMP has been working with the ACIS and Calibration teams to schedule calibration source measurements in science orbits, to ensure that the calibration exposure goals are achieved.
  - This gets a bit tricky, since the amount of exposure time that will come from radiation zones is uncertain.

Tool/Process/Limit Updates

Other Updates

- ACIS Heater Setpoint:
  - ACIS is investigating the potential benefits of lowering the set-point at which the ACIS heater turns on. If the ACIS focal plane is allowed to reach a lower temperature, then the maximum dwell time after reaching this lower limit may be improved.

- “Hot” ACIS Observations:
  - It was determined that observations done with only the ACIS-S3 chip on that also are expected to accumulate <300 total source counts, **OR** observations done with the HETG, are not impacted by larger the calibration uncertainties associated with a higher ACIS focal plane temperature. (Internally we refer to these as “ACIS-H” observations.)
  - The increased focal plane temperature limit allows for longer dwell times for such observations. This benefit has been included in the SOTMP thermal model that is used to build the LTS.

- Working on assistive scheduling software for weekly planning.

Tool/Process/Limit Updates

For the Future: Star Field Checker Tool

- As the temperature limit of the ACA is increased, the limiting flux of stars that can be used for acquisition and guiding also increases, due to the increased noise in the ACA detector.
- As a result, any given field in the sky becomes less likely to contain a sufficient number of stars bright enough for acquisition and guiding.
- Targets in fields without enough bright stars need to be observed with ACA temperatures that are lower than the global planning limit, so fainter stars can be used. This impacts the thermal balance, and limits the time of year at which we can schedule some targets (since the star field is a function of roll angle).
- As the baseline ACA temperature increases, some fields may become impossible to observe with Chandra.

Tool/Process/Limit Updates

For the Future: ACA Star Field Checker Tool

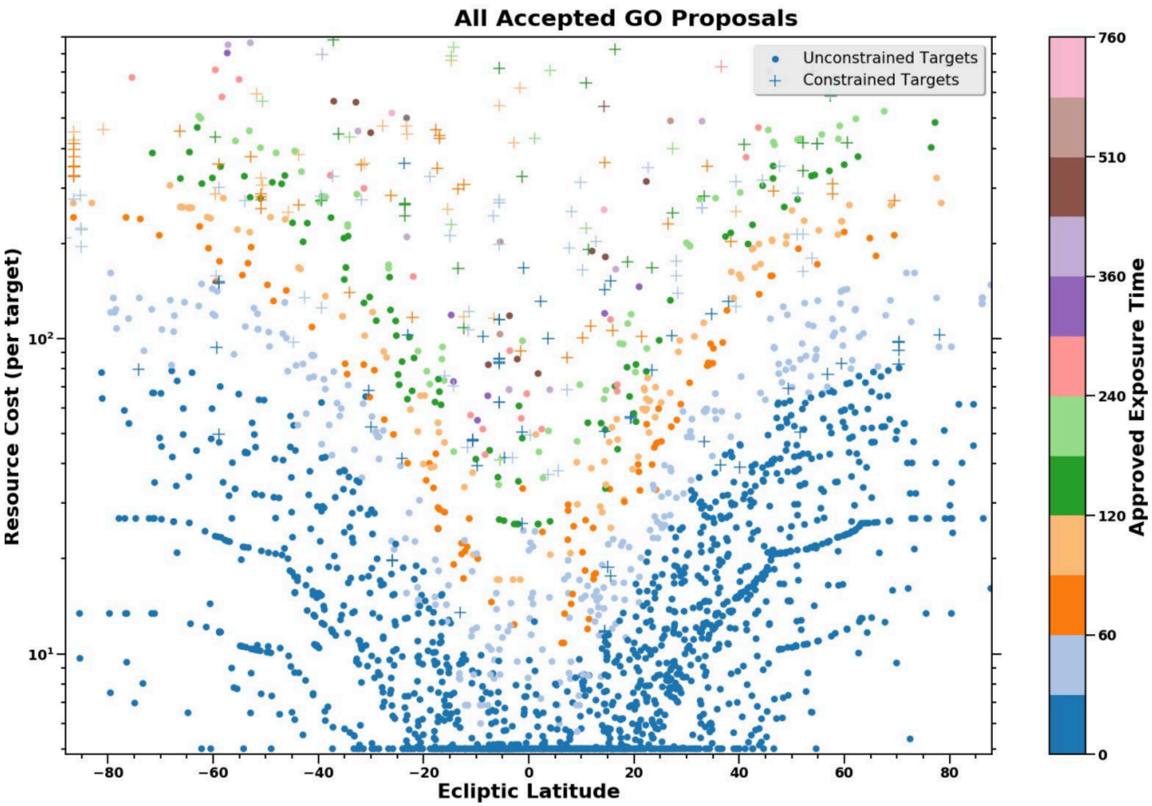
- The quality of the star field for a given target should be checked at the time of proposal submission. In addition, there should be a stand alone webtool, outside of CPS, that the community can use to evaluate star fields.
- It was determined that this is not top priority for the Cycle 24 CfP, partially due to the heating relief from the IRU switch and zone 5 heater turn-off. However, it should be done for Cycle 25.
- This “Star Field Checker Tool” is currently under development. A command -line version of this tool already exists, all that remains is for Data Systems to incorporate the tool into CPS and a separate webpage. (The stand-alone Resource Cost Calculator is in a similar state.)

Tool/Process/Limit Updates

- History of recent thermal limit changes

Model	Date of most recent update	Planning limit relaxations in past year
ACA	2021 Jul	-7.8C -> -7.1C -> -6.5C ->- 5.8
MUPS	2020 Apr	210F Limit Unchanged
OBA	2021 Jun	100F -> 103F
Tank	2021 Jul	105F -> 110F -> 115F
PLINE	2020 May	50F -> 55F -> 50F
DEA	2020 Dec	36.5C -> 37.5C
ACIS FP	2020 Jun	ACIS-I: -112C ACIS-S: -111C ACIS-H: -109C

Tool/Process/Limit Updates: Resource costs

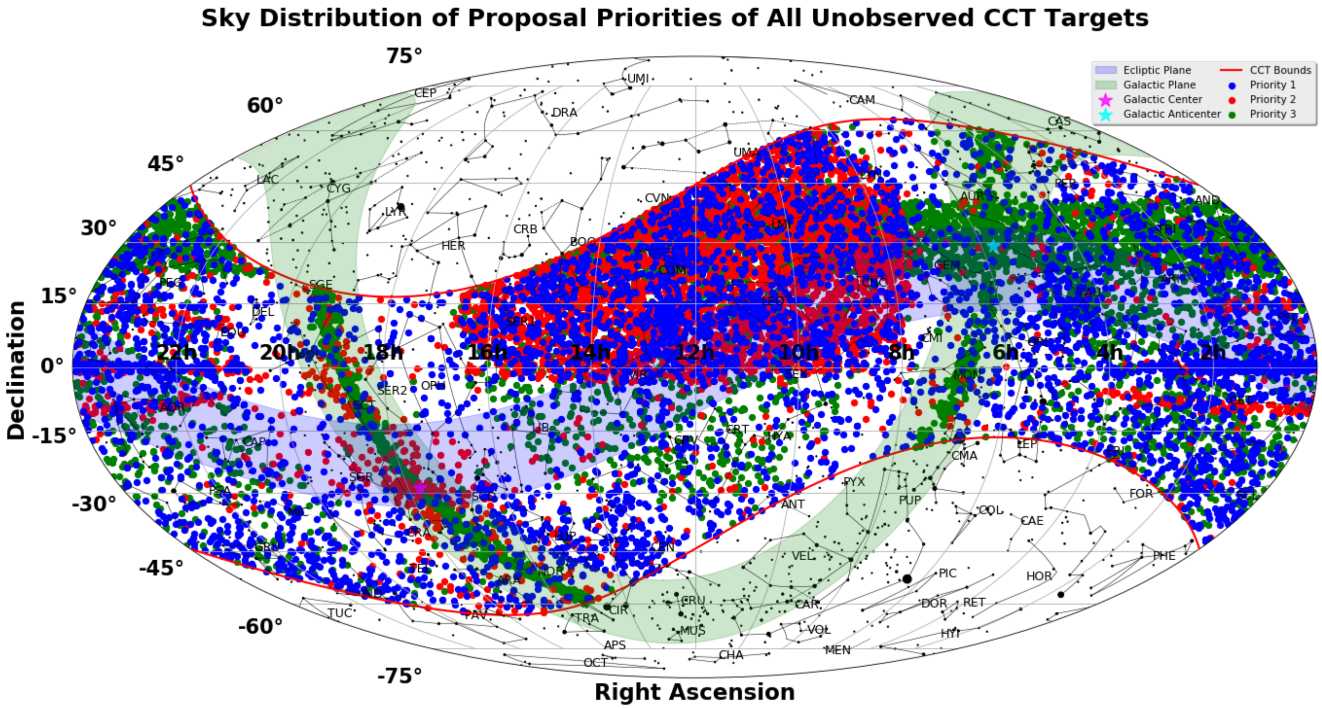


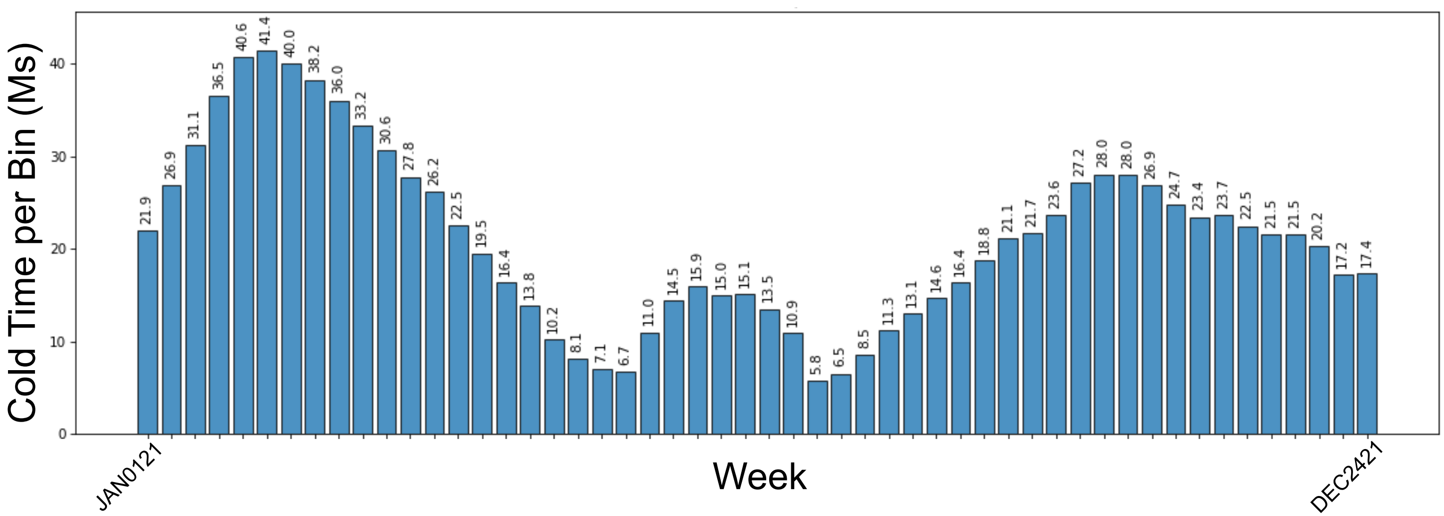
Resource Cost (RC) values for observing programs from *Chandra* Cycles 14-22.

- Circles correspond to observations without constraints, for which RC values depend only on ecliptic latitude (X-axis) and exposure time (color bar at right).
- Crosses correspond to targets with observing constraints

- Introduced in cycle 22.
- Replaces "constraint categories" (easy/average/difficult) used in previous cycles.
- Calculated for all non-TOO targets.
- On current (arbitrary) scale, peer review assigns total cost ~32,000.
- Resource cost calculator provides real-time user feedback during proposal preparation
- Updated to scale linearly with exposure time, as opposed to exposure time segments of fixed size

Chandra Cool Targets (CCTs)





- 22 programs
- Include:

galaxy clusters, ULXs quasars, AGN, HMXBs CVs, SFRs, cool stars, survey counterparts, radio galaxies, star clusters, Fermi sources, dwarf galaxies, symbiotic stars

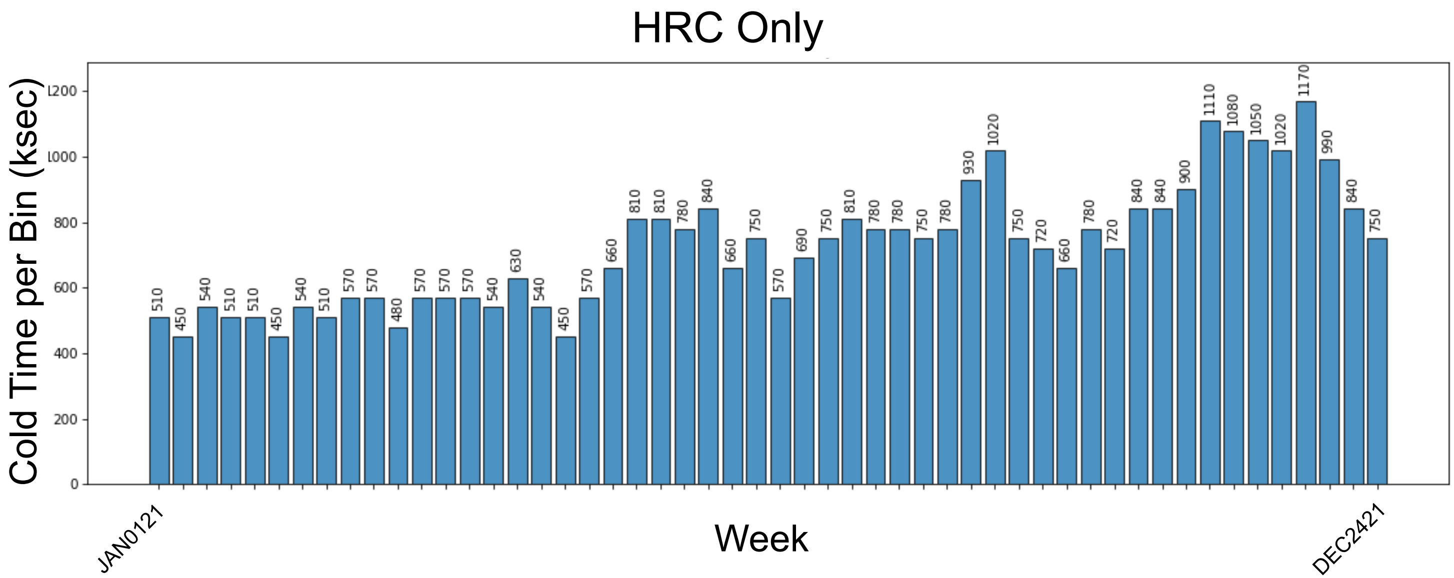
10 ks ≤ t ≤ 35 ks; |b| < 40º

- Includes:
  - ~19,000 targets
  - ~400 Ms in time

- Adequate cooling time in any week

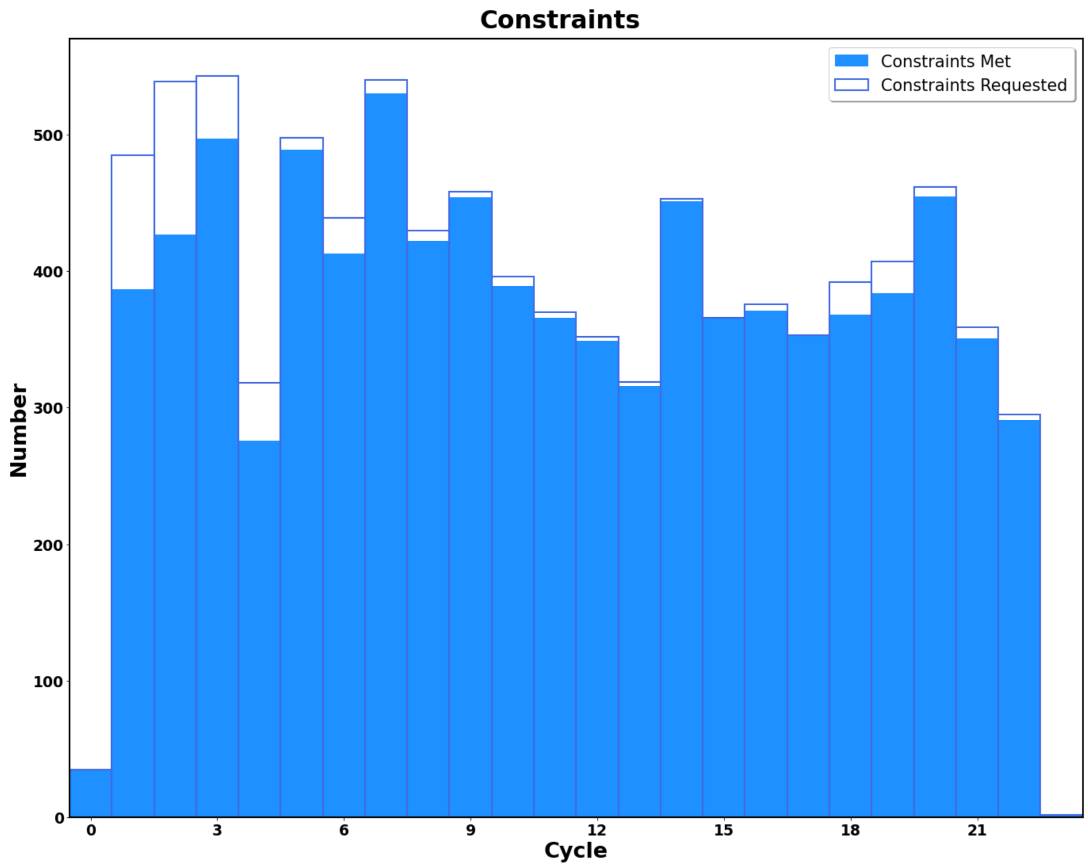
- CCT observation rate:
  - has been ~1Ms/yr
  - is anticipated to continue at about this rate

Chandra Cool Targets (CCTs)



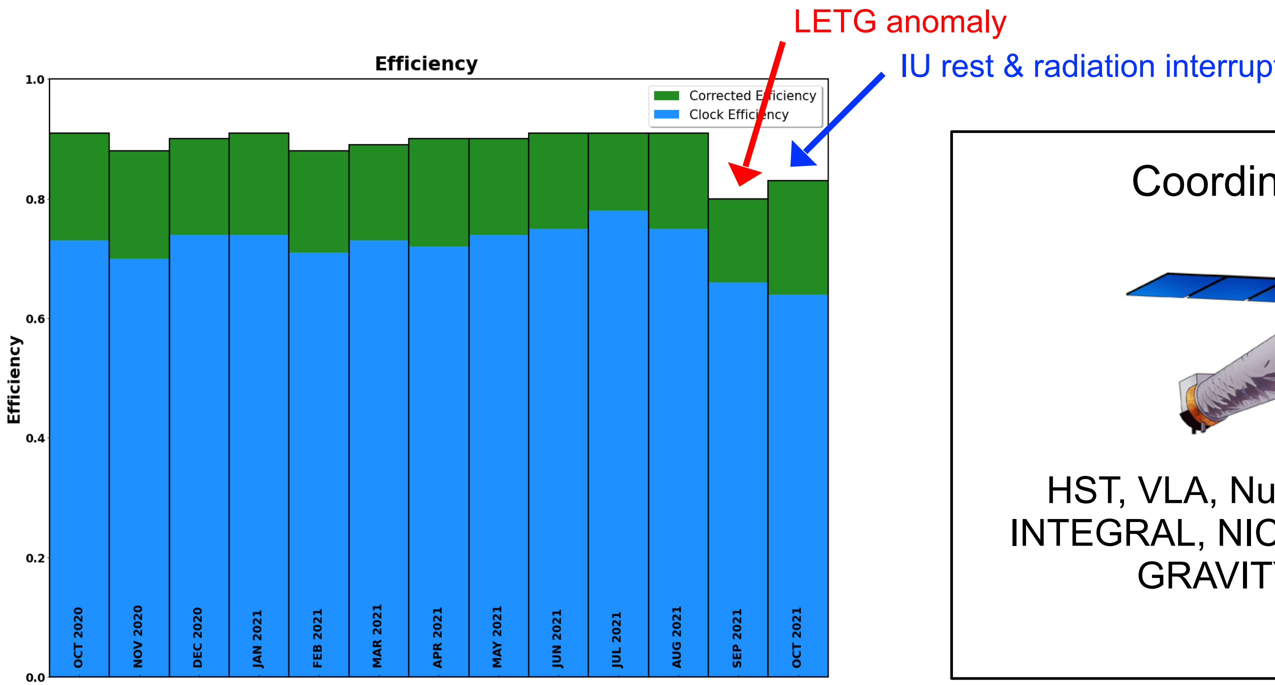
- Recall that cold HRC observations are particularly useful for thermal management, since ACIS is the main limiting factor at high pitch angles.
- There is a good amount of HRC cold time per week remaining in the CCT program.
- However, **all** of these remaining observations are 30 ks, which is typically longer than desired for nominal planning, since it can unnecessarily displace time from GO programs or unbalance the ACIS heating budget for the week.

Constraints ~~and Preferences~~

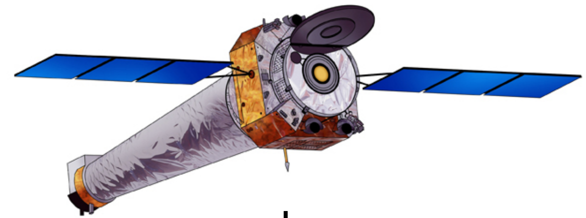


- Observing preferences are no longer supported, as of Cycle 22.
- Continue to meet observing constraints successfully with high observing efficiency.
- Difficulty associated with meeting constraints is increasing due to spacecraft thermal limitations (e.g., uninterrupt constraints)

Observation Scheduling



Coordinated Observations



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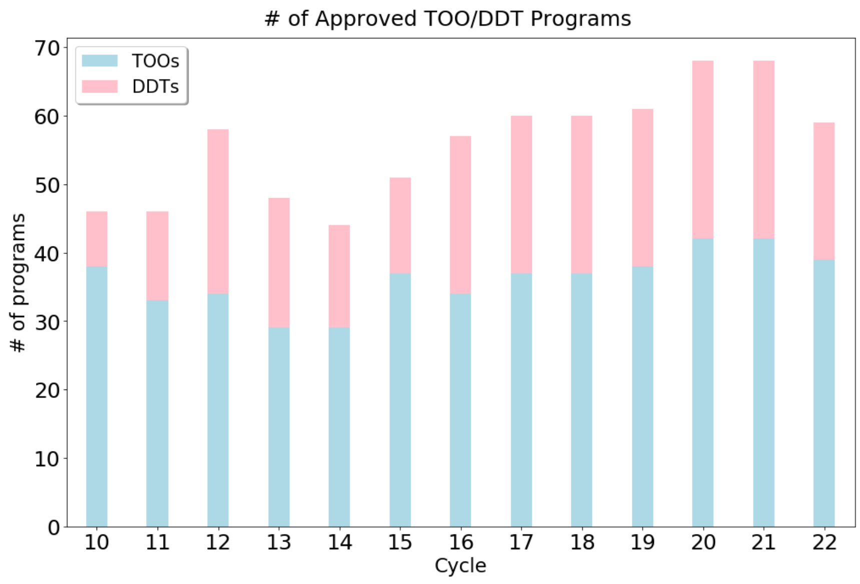
HST, VLA, NuSTAR, Swift, XMM, Astrosat, INTEGRAL, NICER, EHT, ATCA, Gemini, VLTI/ GRAVITY, Effelsberg, eROSITA

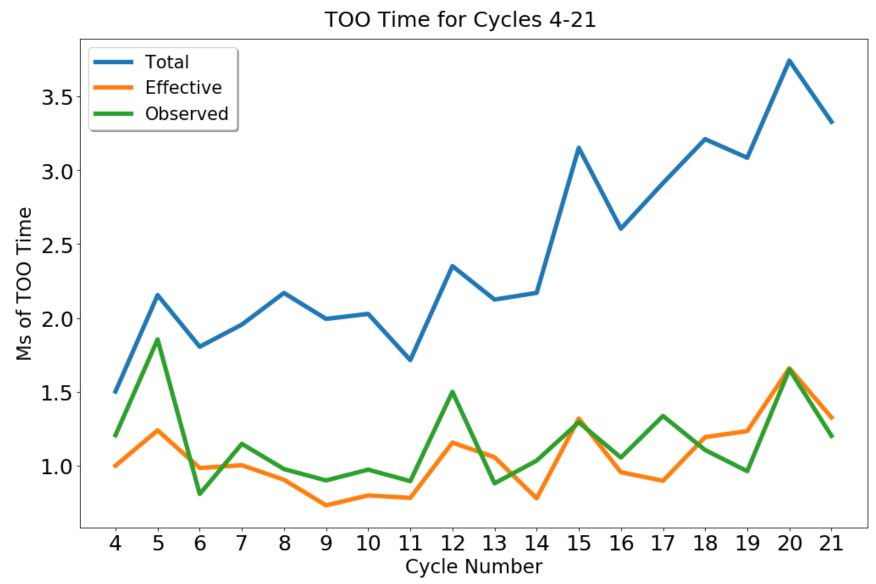
From Oct. 1, 2020 - Nov. 1, 2021:

- Scheduled: 1291 observations (24.9 Ms)
- Executed:
  - 59 TOO observations (1.57 Ms)
  - 33 DDT observations (723 ks)
    - ✧ interrupted 9 operating loads for TOO/DDT support

- Chandra Coordinations (Oct. 1 2020 - Nov. 1 2021):
  - 110 observations for 2.6 Ms

TOO/DDT Observations: Historical Performance

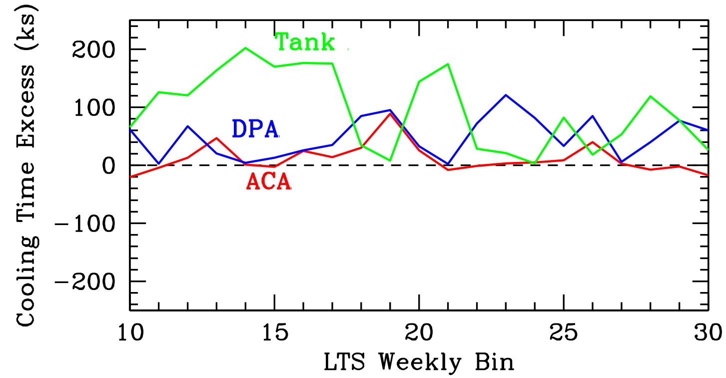




Historical TOO/DDT performance has been very steady despite evolution of thermal constraints over more than a decade.

- This has been done by continued development of tools and procedures, and this process continues for both regular planning and TOOs.
- We anticipate continued support at levels similar to historical levels, but with some modifications to response times and cadences.

TOO/DDT Observations: Impacts on LTS



Thermal balance

Momentum balance

Segment: 35 limit: 7.00d, used 5.27d = 75.29% 12-Oct-2020 00h to 19-Oct-2020 00h (UT)

#Orbits: 2 Orbit Time: 481.70ks LTS Time: 453.66ks #Targets: 20

Thermal Budget:		cold budget
aca	:	+4.6
ipstank	:	+23.0
mups	:	-8.8
dpa	:	+89.0

momentum axes		momentum totals	
P_x :	+8.75	P_tot :	19.87
P_y :	-6.76	P_bal :	9.87
P_z :	-16.51		

seq#		obs	name	time	RA	dec	Roll	Range	Pitch	Range	SI	R	O	grat	observer	Type	AO	OR#	SF	TC	RC	PC	UC	PU	Mlt	CRem
201298	H	22340	Orion Nebula Cluster	27.0	83.819	-5.390	79.6	75.5	112.6	118.5	ACIS-S	6	2	HETG	Schulz	GO	21	0	N	N	N	N	N	N	N	N
201298	H	22997	Orion Nebula Cluster	25.1	83.819	-5.390	79.6	75.5	112.6	118.5	ACIS-S	6	2	HETG	Schulz	GO	21	0	N	N	N	N	N	N	N	N
201298	H	24832	Orion Nebula Cluster	29.0	83.819	-5.390	79.6	75.5	112.6	118.5	ACIS-S	6	2	HETG	Schulz	GO	21	0	N	N	N	N	N	N	N	N
201298	H	24834	Orion Nebula Cluster	28.0	83.819	-5.390	79.6	75.5	112.6	118.5	ACIS-S	6	2	HETG	Schulz	GO	21	0	N	N	N	N	N	N	N	N
201443	C	24838	2RXS J012535.1+23303	20.0	21.399	23.511	166.4	191.2	163.5	166.3	ACIS-S	1	0	NONE	Guenther	CCT	21	0	N	N	N	N	N	N	N	N
402250		23472	M51	35.0	202.458	47.204	354.0	1.9	54.8	57.3	ACIS-S	6	5	NONE	Earnshaw	GO	22	0	N	S	N	N	N	N	N	N
503167	H	24635	SNR 0509-67.5	35.0	77.379	-67.521	59.2	52.3	94.0	93.6	ACIS-S	4	3	NONE	Williams	GO	21	0	N	N	N	N	N	N	N	N
503236	8	23561	SN 2013ge	12.0	158.702	21.662	56.9	59.2	48.0	54.7	ACIS-S	2	1	NONE	Patnaude	GO	22	0	N	N	N	N	N	N	N	N
601536		23635	SDSSJ011729.1-084404	10.0	19.371	-8.734	6.5	345.9	163.7	160.6	ACIS-S	3	2	NONE	Levan	GO	22	0	Y	N	N	N	N	N	N	N
601536		24835	SDSSJ011729.1-084404	30.0	19.371	-8.734	6.5	345.9	163.7	160.6	ACIS-S	3	2	NONE	Levan	GO	22	0	Y	N	N	N	N	N	N	N
703941		24753	MCG -5-23-16	42.0	146.917	-30.949	105.5	98.6	52.7	56.8	ACIS-S	6	2	HETG	Zoghbi	GO	21	0	N	S	N	N	N	N	N	N
703942		22554	MCG -5-23-16	31.0	146.917	-30.949	105.5	98.6	52.7	56.8	ACIS-S	6	2	HETG	Zoghbi	GO	21	0	N	S	N	N	N	N	N	N
703942		24833	MCG -5-23-16	29.0	146.917	-30.949	105.5	98.6	52.7	56.8	ACIS-S	6	2	HETG	Zoghbi	GO	21	0	N	S	N	N	N	N	N	N
704144	8	23732	UGC01958	5.6	37.245	28.146	134.3	143.1	152.2	158.1	ACIS-S	4	0	NONE	Foord	GO	22	0	N	N	N	N	N	N	N	N
704236	8	23824	SDSS J0248+1913	5.0	42.203	19.225	112.8	115.0	153.3	160.2	ACIS-S	6	5	NONE	Pooley	GO	22	0	N	N	N	N	N	N	N	N
704244		23832	J0252-0503	15.0	43.069	-5.059	64.0	51.3	151.6	155.8	ACIS-S	6	2	NONE	Wang	GO	22	0	N	N	N	N	N	N	N	N
704244		24472	J0252-0503	30.0	43.069	-5.059	64.0	51.3	151.6	155.8	ACIS-S	6	2	NONE	Wang	GO	22	0	N	N	N	N	N	N	N	N
704244		24473	J0252-0503	14.0	43.069	-5.059	64.0	51.3	151.6	155.8	ACIS-S	6	2	NONE	Wang	GO	22	0	N	N	N	N	N	N	N	N
704244		24836	J0252-0503	15.0	43.069	-5.059	64.0	51.3	151.6	155.8	ACIS-S	6	2	NONE	Wang	GO	22	0	N	N	N	N	N	N	N	N
704244		24837	J0252-0503	16.0	43.069	-5.059	64.0	51.3	151.6	155.8	ACIS-S	6	2	NONE	Wang	GO	22	0	N	N	N	N	N	N	N	N

Cycle | Stars | Constraints | Coordinations

- Targets displaced by TOO need to be rescheduled.
  - Each displaced target disrupts delicately-balanced LTS; rescheduled targets delayed.
- TOO may conflict with constrained target.
  - Conflict resolution can disrupt LTS

TOO/DDT Responses and Planning

- Very Fast TOO response times could be delayed by up to10 hours beyond historical times in order to pre-cool.
- Anti-TOOs are TOOs
  - Pulling a TOO or its follow-up after scheduling requires a similar effort as starting a new TOO.

- Approach to TOO follow-ups has been changed effective cycle 22
  - Now, follow-ups schedulable at time of trigger count as ½ trigger against the cycle quota; follow-ups that depend on results of an earlier TOO are proposed as separate TOOs
- TOO/DDT programs delay GO observations.
  - Harsh reality is that bumped targets can no longer routinely be rescheduled into a nearby week.

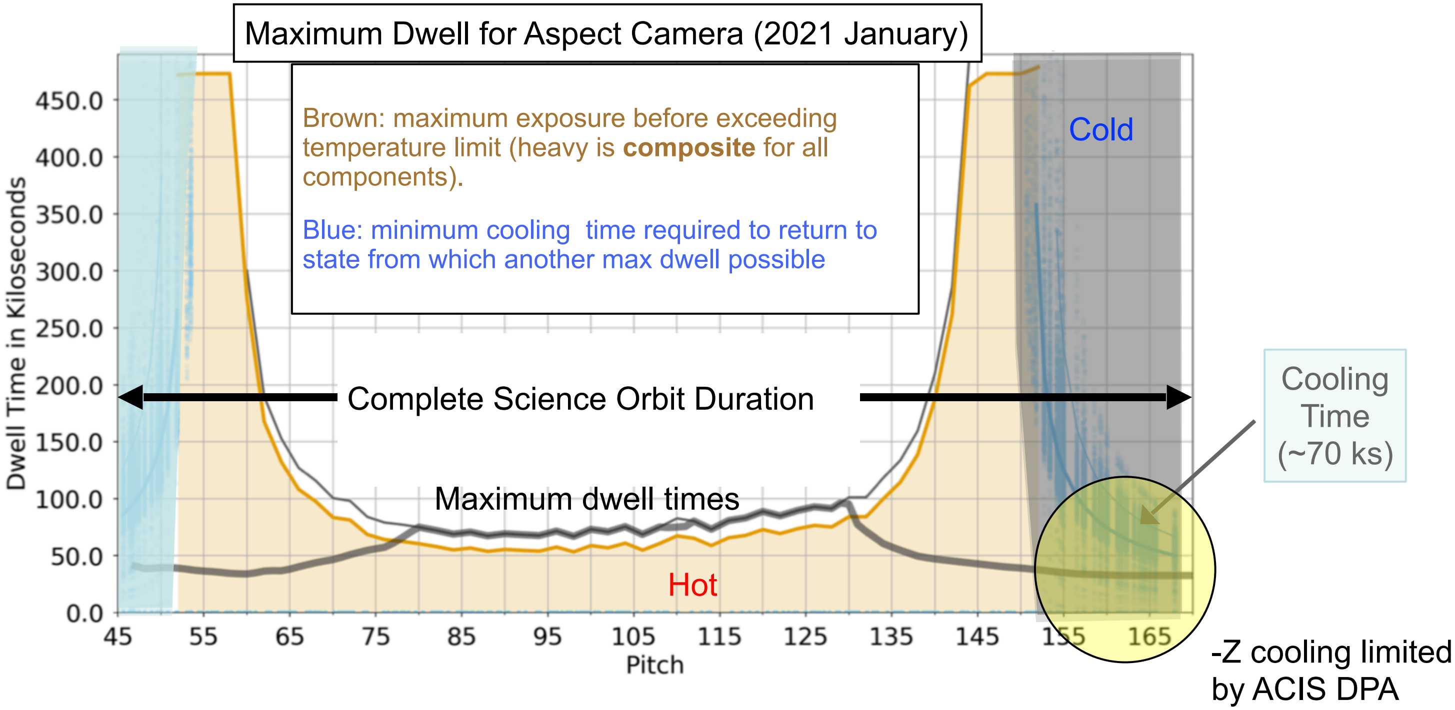
Backup Slides

TOO/DDT Observations: Planning Impacts

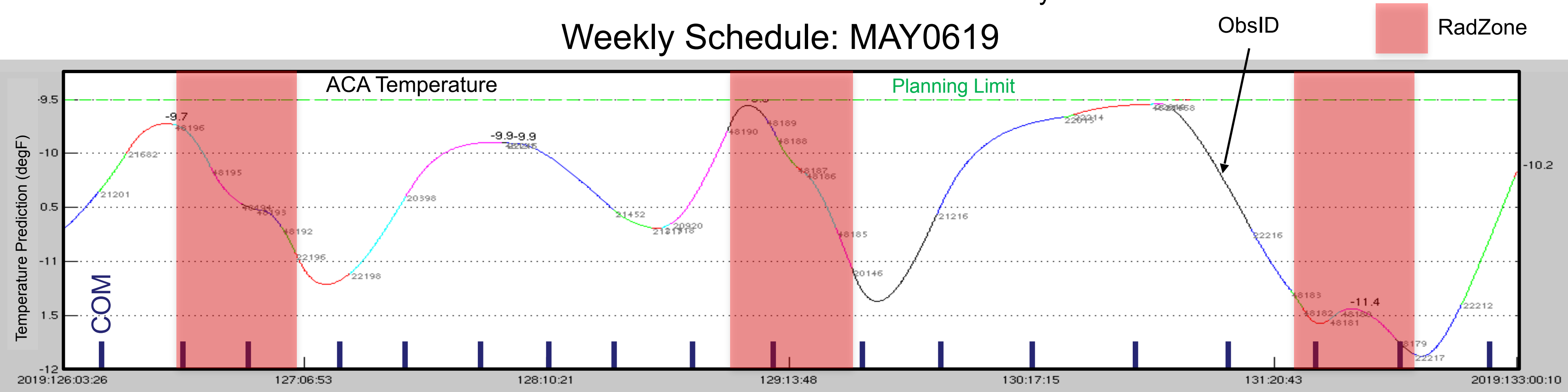
Snapshot of Planning Process

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Weekend
Schedule Planning	SOTMP Reviews LTS Bin		Preliminary Schedule Build			
	On-call for previous week's loads, performing all FOTMP Reviews					
Preliminary Schedule	Finalize Preliminary Schedule		Internal FOTMP Prelim Review ---- Rebuild Prelim*	ACA Pre-review of Prelim ---- Rebuild Prelim*	Deliver Prelim to SOTMP ---- SOTMP Review	
Schedule Review	SOTMP Delivers Final ORL ---- FOT Builds Final Schedule	FOTMP Builds Official Loads ---- FOTMP Review	Loads Released for Review ---- Load Review	Subsequent Load Builds and Load Reviews, if necessary.		
Schedule Running	LOADS ONBOARD AND RUNNING (Planner who built loads is on-call, performing all FOTMP reviews, and already starting the next schedule's first week)					

Thermal Balance: A Summary



Weekly Schedule: MAY0619



Note: COM times are illustrative only.