Mission Planning Updates

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Overall Context for Mission Planning

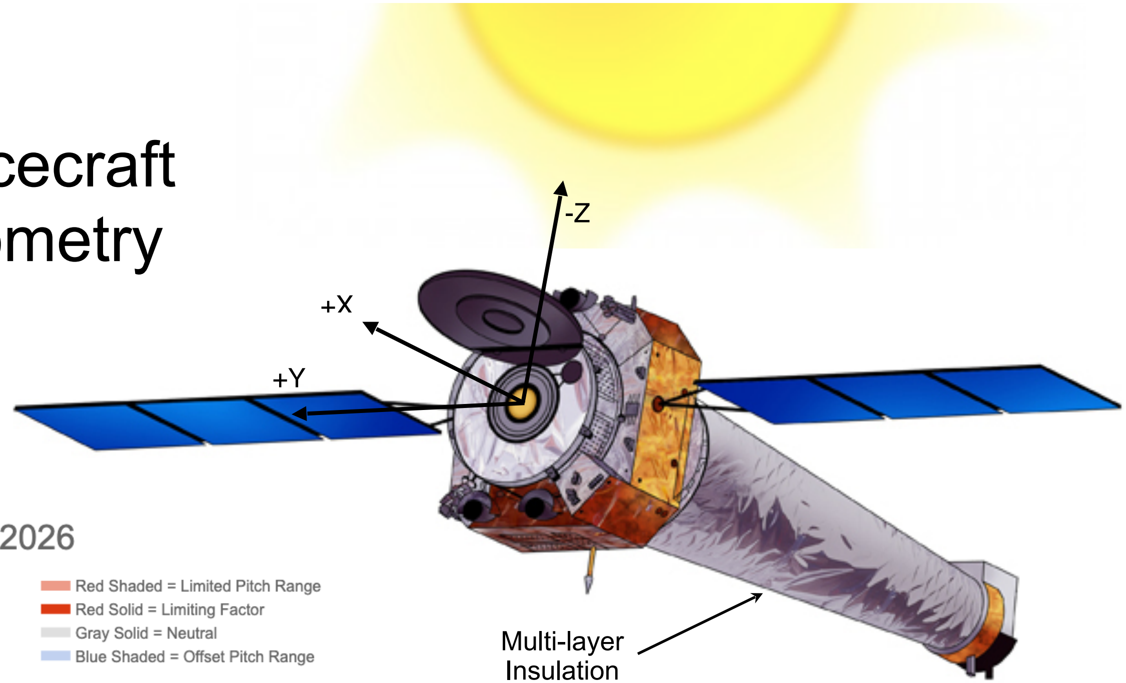
Goal:
Maximizing the science return of the mission in the presence of constraints:

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

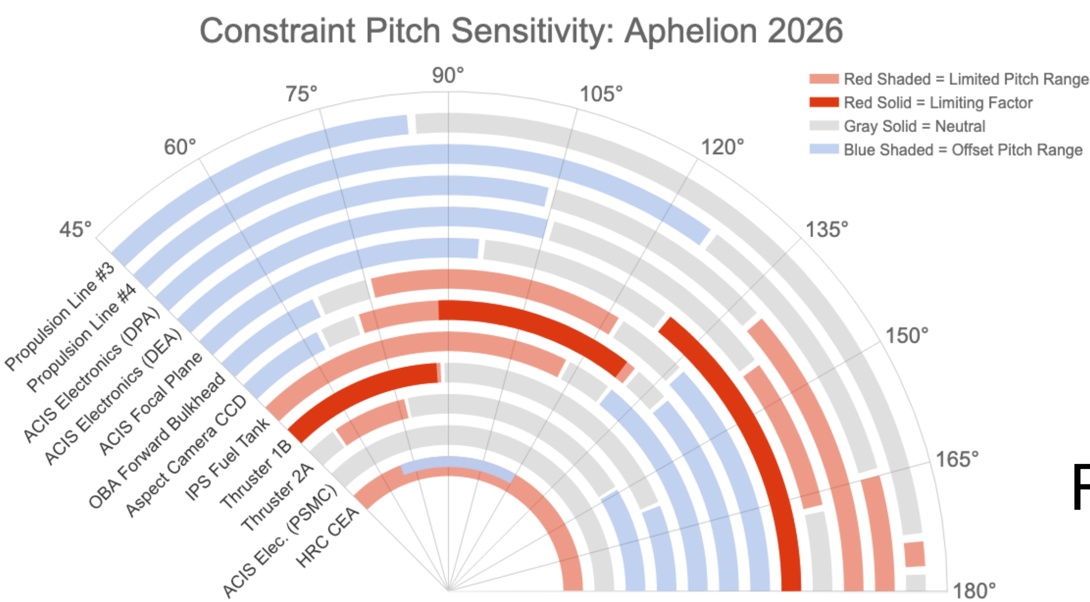
- Engineering constraints, e.g.,
  - *thermal constraints*
  - star field constraints
  - momentum management
  - Sun, Moon, Earth, bright X-ray source avoidance

Chandra Thermal Restrictions

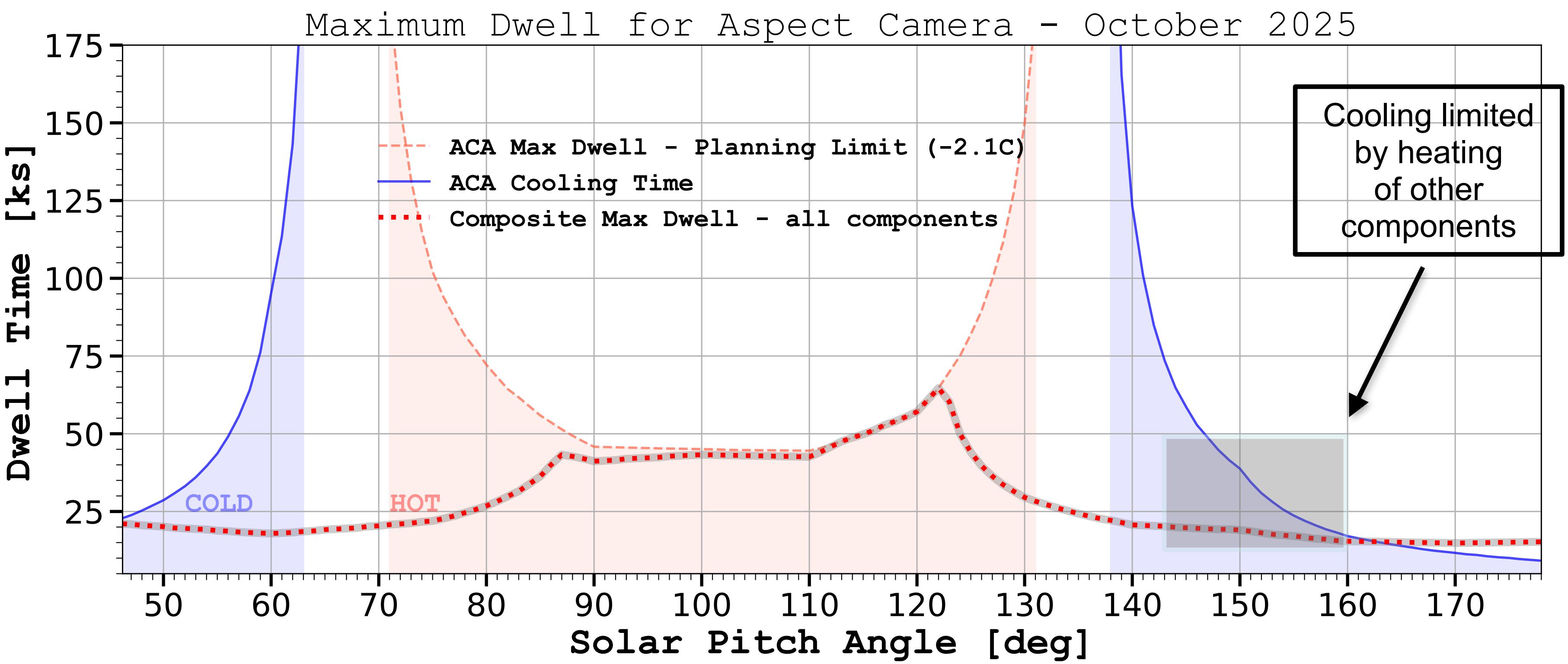
Spacecraft Geometry



Thermal Restrictions



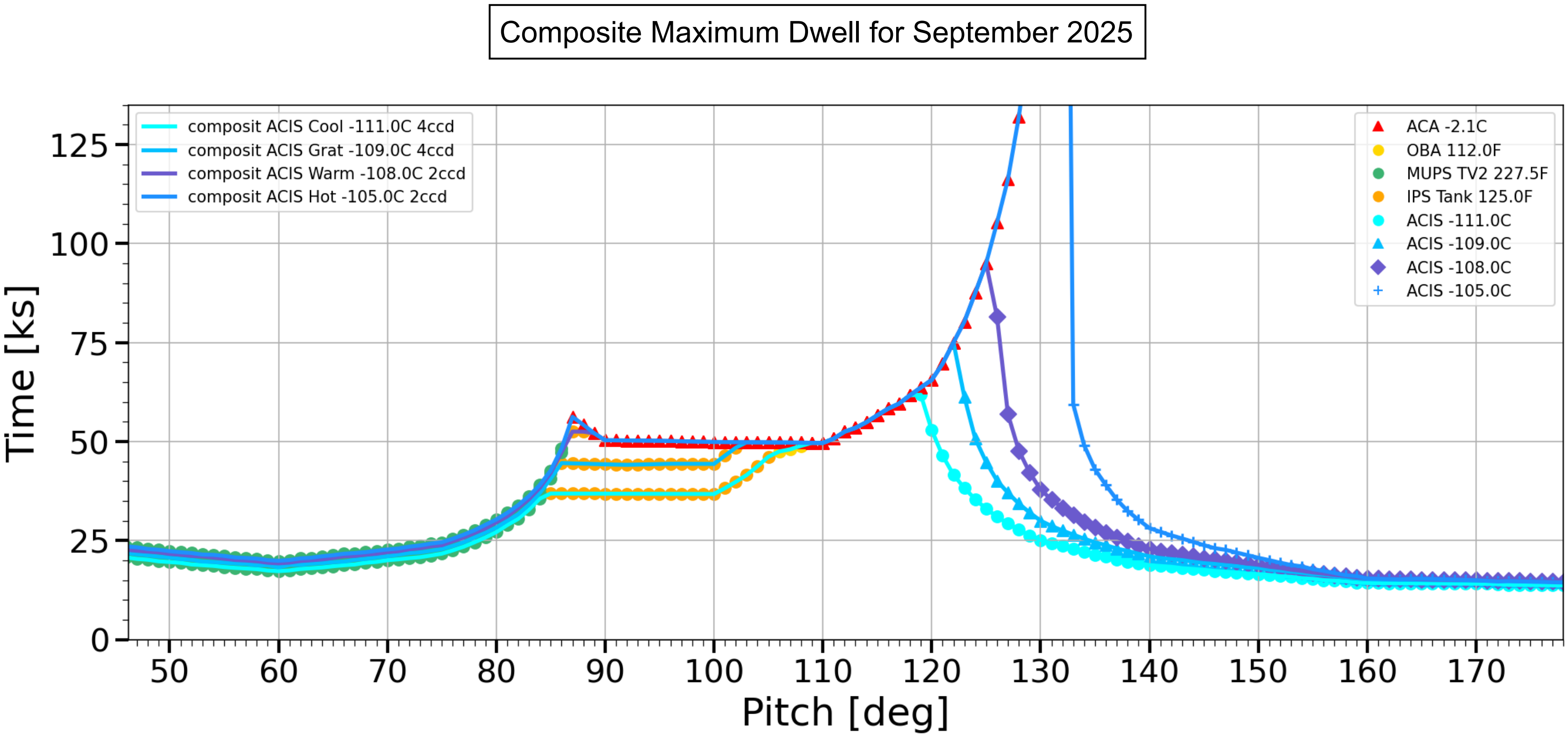
Thermal Balance: A Summary



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

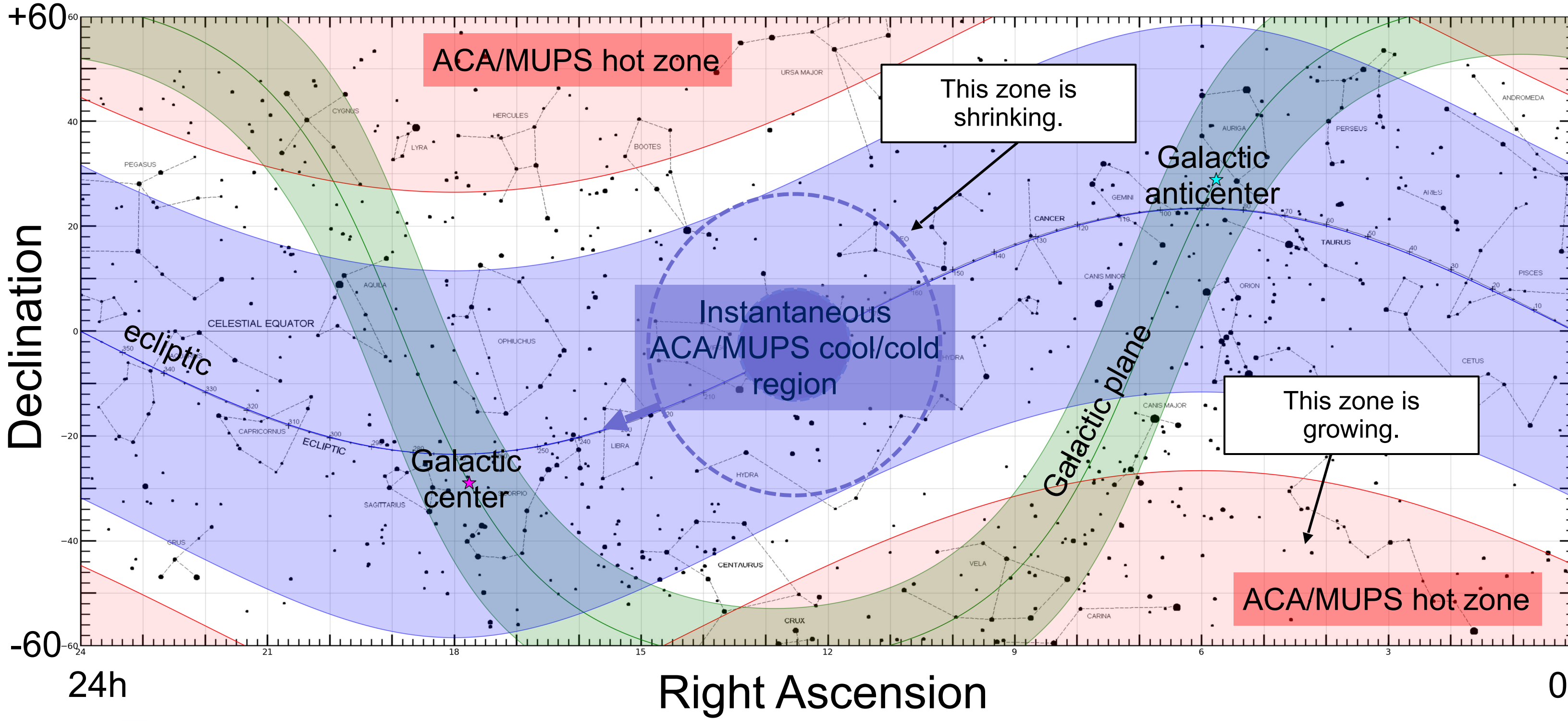
Blue: minimum cooling time required to return to state from which another max dwell possible

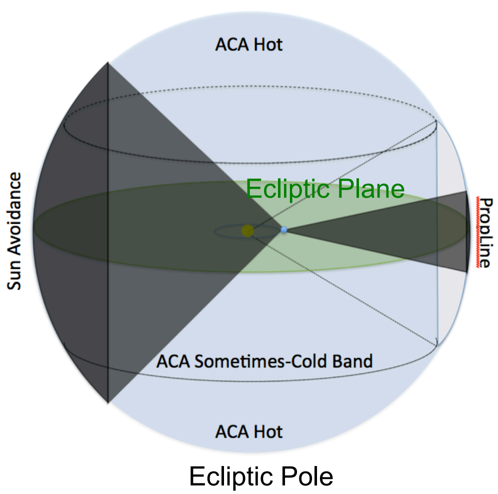
Thermal Balance: A Summary



- Thermal management has largely become about balancing MUPS temperature versus ACIS FP temperature, as they heat and cool at opposite ends of the pitch extremes
- We continue to work hard to stay ahead of rising temperatures with component planning limit increases, wherever possible.

Constraints: Sky View





- The sometimes-cool/cold ACA/MUPS (-Z) region covers a band in the sky
- Although the story is no longer dominated by the ACA (rather by MUPS vs ACIS), the anti-Sun region is still extremely valuable for thermal management
- The cool region is shrinking and the hot ones are growing with time

Impact on the Long Term Schedule

Thermal balance   Momentum balance   Sky distribution

Segment: 39 limit: 4.73d, used 4.21d = 89.01% 10-Nov-2025 00h to 17-Nov-2025 00h (UT) antisun plot skybal plot

#Orbits: 3 Orbit Time: 409.05ks LTS Time: 363.00ks HRC Time: 0.00ks skybal: -110.90 #Targets: 11

Thermal Budget:	cold budget
aca	: +69.3
mups	: +3.8
ipstank	: +80.8
dpa	: +8.4
hrc	: +123.7

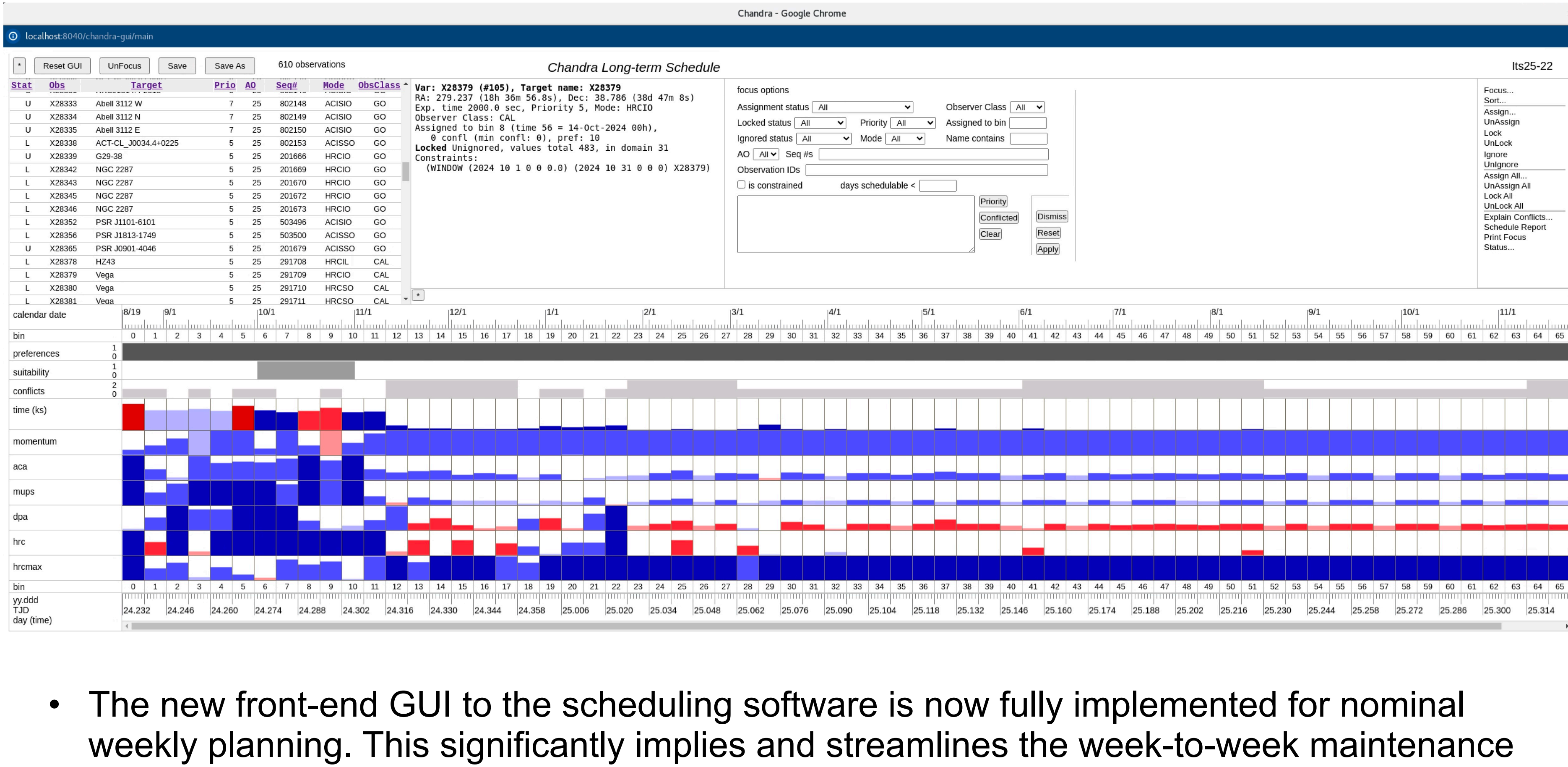
momentum axes		momentum totals	
P_x :	+6.80	P_tot :	7.89
P_y :	-1.63	P_bal :	-7.11
P_z :	-3.66		

seq#	obs	name	time	RA	dec	Roll	Range	Pitch	Range	SI	R	O	grat	observer	Type	AO	OR#	SF	TC	RC	PC	UC	PU	SC	Mlt	CRem	FP
503689	31211	SN 2018ivc	40.0	40.672	-0.009	346.5	330.0	162.4	158.0	ACIS-S	4	2	NONE	Chandra	GO	27	0	N	N	N	N	N	N	N	N	N	-105.0
601634	29639	IC1954	52.0	52.881	-51.905	8.2	0.8	110.7	109.2	ACIS-S	4	0	NONE	Mathur	CLP	25	0	N	N	N	N	N	N	N	N	N	-111.0
601647	30161	NGC3626	30.0	170.016	18.357	60.0	61.8	64.6	71.4	ACIS-S	4	0	NONE	Mathur	CLP	25	0	-5.1	N	N	N	N	N	N	N	N	-111.0
601647	30162	NGC3626	30.0	170.016	18.357	60.0	61.8	64.6	71.4	ACIS-S	4	0	NONE	Mathur	CLP	25	0	-5.1	N	N	N	N	N	N	N	N	-111.0
601730	31231	SDSS J031426.10-0108	30.0	48.609	-1.146	11.2	350.5	161.4	159.6	ACIS-S	2	0	NONE	Oskinova	GO	27	0	0.2	N	N	N	N	N	N	N	N	-108.0
705017	31488	NGC 4579	19.0	189.432	11.818	51.2	54.3	45.4	52.1	ACIS-S	6	2	HETG	Shi	GO	25	0	0.2	N	N	N	N	N	N	N	N	-109.0
705224	29936	NGC 1358	30.0	53.415	-5.090	20.6	3.1	156.3	155.9	ACIS-S	5	1	NONE	Marchesi	GO	26	0	0.3	S	N	N	N	N	Y	Y	N	-108.0
705273	29985	MCG-5-23-16	32.0	146.917	-30.949	80.9	75.9	71.2	76.4	ACIS-S	1	0	HETG	Miller	GO	26	0	N	N	N	N	N	N	N	N	N	-109.0
705279	30224	NGC 4051	20.0	180.790	44.531	43.9	48.8	73.5	78.8	ACIS-S	2	0	HETG	Miller	GO	26	0	N	N	N	N	N	N	N	N	N	-109.0
802196	29631	Perseus cluster	50.0	49.951	41.512	168.5	185.2	155.2	157.3	ACIS-I	5	1	NONE	Fabian	CLP	25	0	N	N	N	N	N	N	N	N	Y	-111.0
802201	30377	Abell 795	30.0	141.022	14.173	72.0	71.8	88.5	95.5	ACIS-S	4	2	NONE	UBERTOSI	GO	26	0	N	N	N	N	N	N	N	N	N	-108.0

Cycle   Star field   Constraints   Coordinations

- Constructing the LTS is extremely challenging. Auto-scheduling software, developed in cooperation with a software team at STScI, allowed the continued generation of efficient schedules. Additionally, the new front-end GUI significantly streamlines this process.
- Construction of the Cycle 27 LTS was completed in October, taking several weeks versus several months prior to the auto-scheduler.

New Spike GUI



- The new front-end GUI to the scheduling software is now fully implemented for nominal weekly planning. This significantly implies and streamlines the week-to-week maintenance of the LTS.

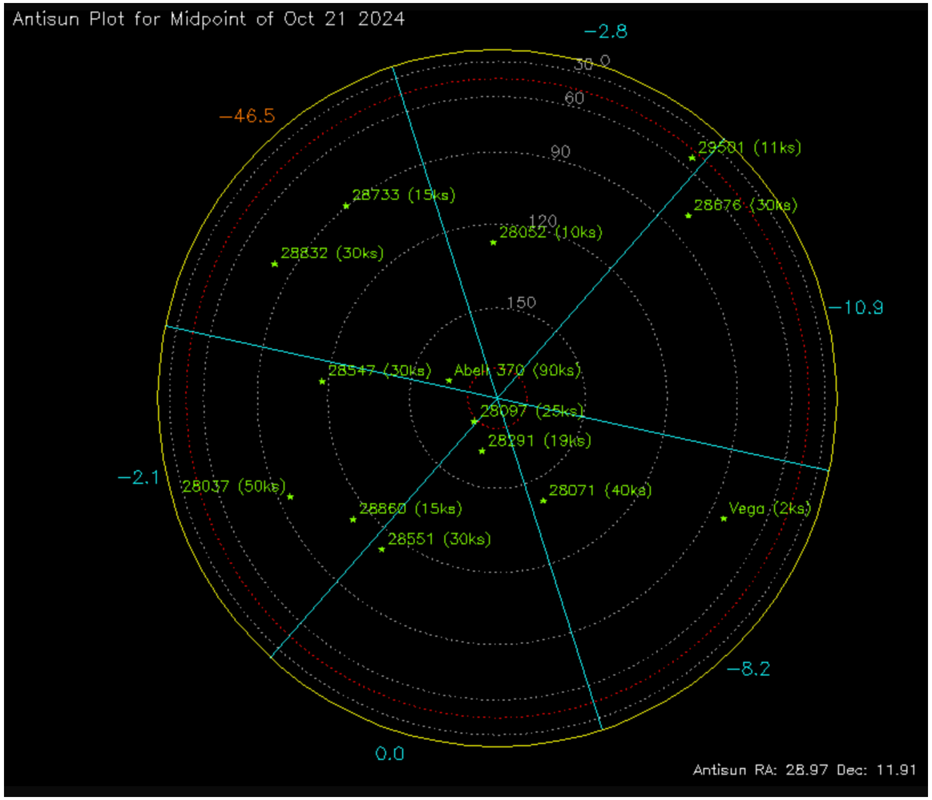
Updates

Welcome to our new Technical Assistant, Joshua Robbins!

Tool / Process Updates

Performance of New "Sky Balance" Metric

- Maneuvering has become increasingly important for detailed weekly planning, due to smaller observation durations and a greater number of splits.
- Previously, the sky distribution of targets in a given week was not quantitatively considered when constructing the Long Term Schedule.
- Developed a metric to quantify the "goodness" of the sky distribution of a collection of targets. The LTS is now designed to keep this metric below some (empirically determined) critical value each week.
- Continues to significantly reduce the amount of LTS time dropped per week (with the bulk of weeks with *no* dropped time), consistent with early results



Tool / Process Updates

Full Implementation Machine Readable ORLs

- We have now fully implemented a new machine-readable ORL format, built around YAML formatted key/value pairs, including new fields to codify the quality of the star field for each target throughout the week.
- This allows automated checking of most scheduling constraints during detailed weekly planning.
- It also sets the groundwork for eventually developing assistive scheduling software, which would help automate the building of weekly schedules (similar to what has been done with Spike for the LTS).

New Handling of Moving Targets

- Previously, moving target coordinates were updated manually when placed/ moved in the LTS.
- In light of recently accepted large programs on moving targets (e.g., ~1 Msec on Jupiter, 140 ks on Mars), switched to pre-computing values for each week in the thermal, momentum, and star field data bases.
- This greatly simplifies assessing the thermal and other resource impacts when considering where to place/move targets in the LTS (and allows the auto-scheduler to do its job more accurately).

Tool / Process Updates

Dynamic Updates to Star Field Tables

- There are fairly frequent updates to the ACA dark current, star catalog, etc. the warrant updating our star field quality tables.
- This must be done for every target, on every day of the year, over a range of allowed roll angles, and is computationally expensive.
- Instead of updating all targets, we adopt an approach where we only update targets scheduled for upcoming weeks along with pool/reserve targets.
- This approach, along with significant speed improvements to our software, allows us to more accurately predict the weekly star field quality for upcoming observations.

Public Short Term Schedule Page Updates

- Minor information content updates to the public-facing Short Term Schedule Page, at the request of the Astrophysics Cross-Observatory Science Support (ACROSS) initiative, to support their efforts to streamline resources for TDAMM science.

Tool / Process Updates

New "Efficiency" and "Lost Science Time" Pages

- Simplifies efficiency tracking to help identify new trends more quickly
- Lost science time previously not tracked.

Efficiency Dashboard (partial)

latest week: OCT2025

name	value
DATE START	2025-10-20
DATE END	2025-10-27
PLANNED EFF	0.829
CORRECTED EFF	0.829
WALLCLOCK EFF	0.627
RADZONE [ks]	147.6
INTERRUPT [ks]	0.0
ORBIT TIME [ks]	457.2
AST [ks]	400.6
OBS TIME [ks]	379.2

thermal model balances			
aca	mups	fp+dpa	hrc
131.3	15.8	72.0	78.8

last 10 weeks AUG1825 - OCT2025

week	planned efficiency	wallclock efficiency	interrupt time	anticipated science time*	observation time
AUG1825	0.919	0.725	0.0	418.1	438.6
AUG2525	0.91	0.713	0.0	415.6	431.5
SEP0125	0.877	0.622	101.5	376.0	376.3
SEP0825	0.858	0.665	0.0	410.4	402.0
SEP1525	0.883	0.678	0.0	406.6	409.9
SEP2225	0.858	0.717	0.0	442.9	433.8
SEP2925	0.835	0.632	0.0	401.0	382.2
OCT0625	0.897	0.681	0.0	402.2	411.8
OCT1325	0.896	0.749	0.0	442.9	453.1
OCT2025	0.829	0.627	0.0	400.6	379.2

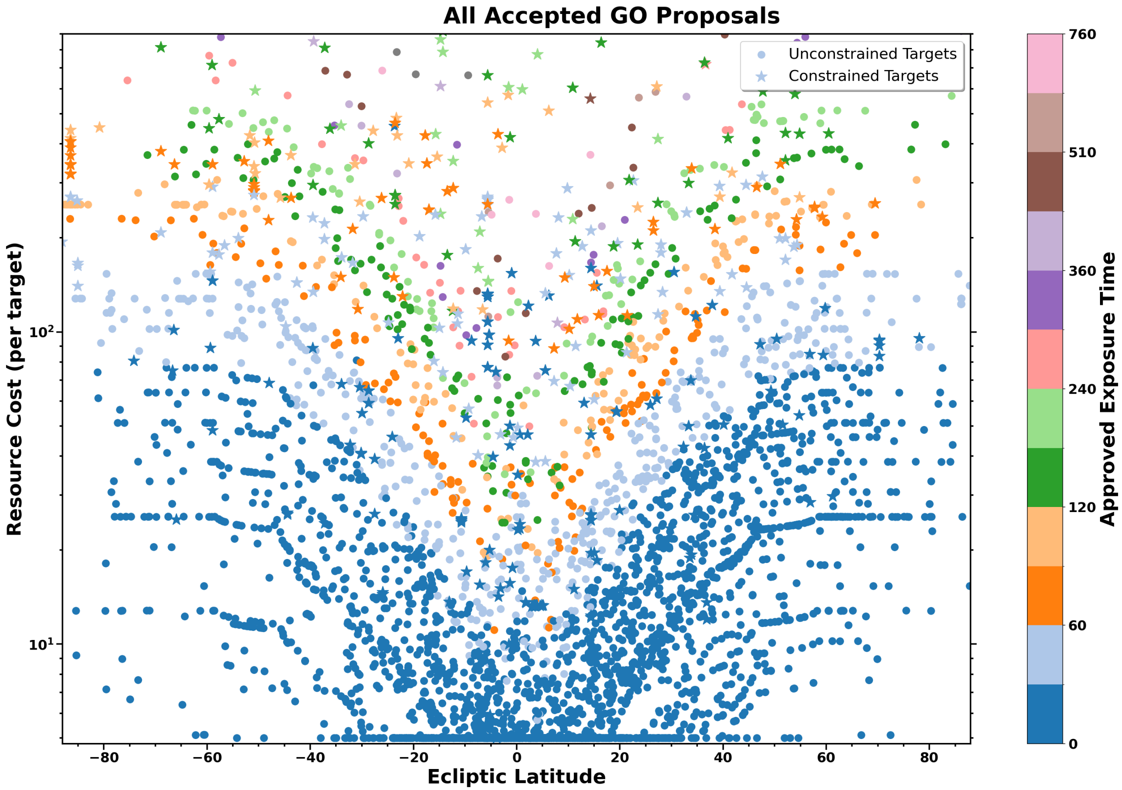
* **anticipated science time** is the total amount of time we expect Chandra to spend doing science observations over the given time period. It is calculated by estimating the amount of time Chandra will spend outside of the radiation zone and multiply it by the planned efficiency over the last 4 months

Lost Science Time Page (partial)

Observations that did not meet science requirements. - Time lost by having to repeat an observation due to a "non-shutdown" anomaly, or incorrect scheduling. Also included in this table are CCT observations canceled because science requirements were not met.

Original Proposal	ObsID	Target Name	Scheduled Time Lost [ks]	Short Schedule Time	Notes
26309059	31036	EP250630b	2	Aug 13 2025 1:43PM	DDT target of opportunity observed at incorrect coordinates (as provided by proposal team because of an error in the Astronomer's Telegram detailing the transient detection)
26800462	29619	A1795	23.3	Jun 12 2025 02:46PM	Observation affected by the June 12 2025 SSR Dump data corruption issue
26200216	30459	Eta Car	14.5	Jun 12 2025 10:05AM	Observation affected by the June 12 2025 SSR Dump data corruption issue
25700279	29619	NGC 4579	18	Jun 12 2025 01:20AM	Observation affected by the June 12 2025 SSR Dump data corruption issue (11ks recovered from a total 29ks)
25700269	28203	FRB20220914A	17	Jan 12 2025 09:52AM	Observation affected by the January 2025 LETG extraction issue
26800045	30375	Abell 795	18	Jan 12 2025 04:17AM	Observation affected by the January 2025 LETG extraction issue
25200530	28953	TW Hya	5	May 05 2024 03:17PM	Coordination constraint with JWST and HST, not met because HST went into safe mode due to a gyro failure
20401069	28975	4U 1908+075	10	Oct 22 2023 12:01PM	Cool Catalog Target observation observed with incorrect coordinates (this CCT was canceled)
22400405	24520	4U 1916-053	10	Sep 01 2021 07:47AM	Observation affected by the September 2021 LETG insertion issue
22400529	23469	M82 X-2	5	Aug 31 2021 11:49PM	Observation affected by the September 2021 LETG insertion issue
14620812	14528	Mkn 766	5	Jul 06 2014 10:11PM	Originally scheduled as an observation of NGC1399 - spacecraft attitude was not as expected and not in agreement with the science instrument configuration (discovered during the 187:2220-2320z comm)

Resource Cost

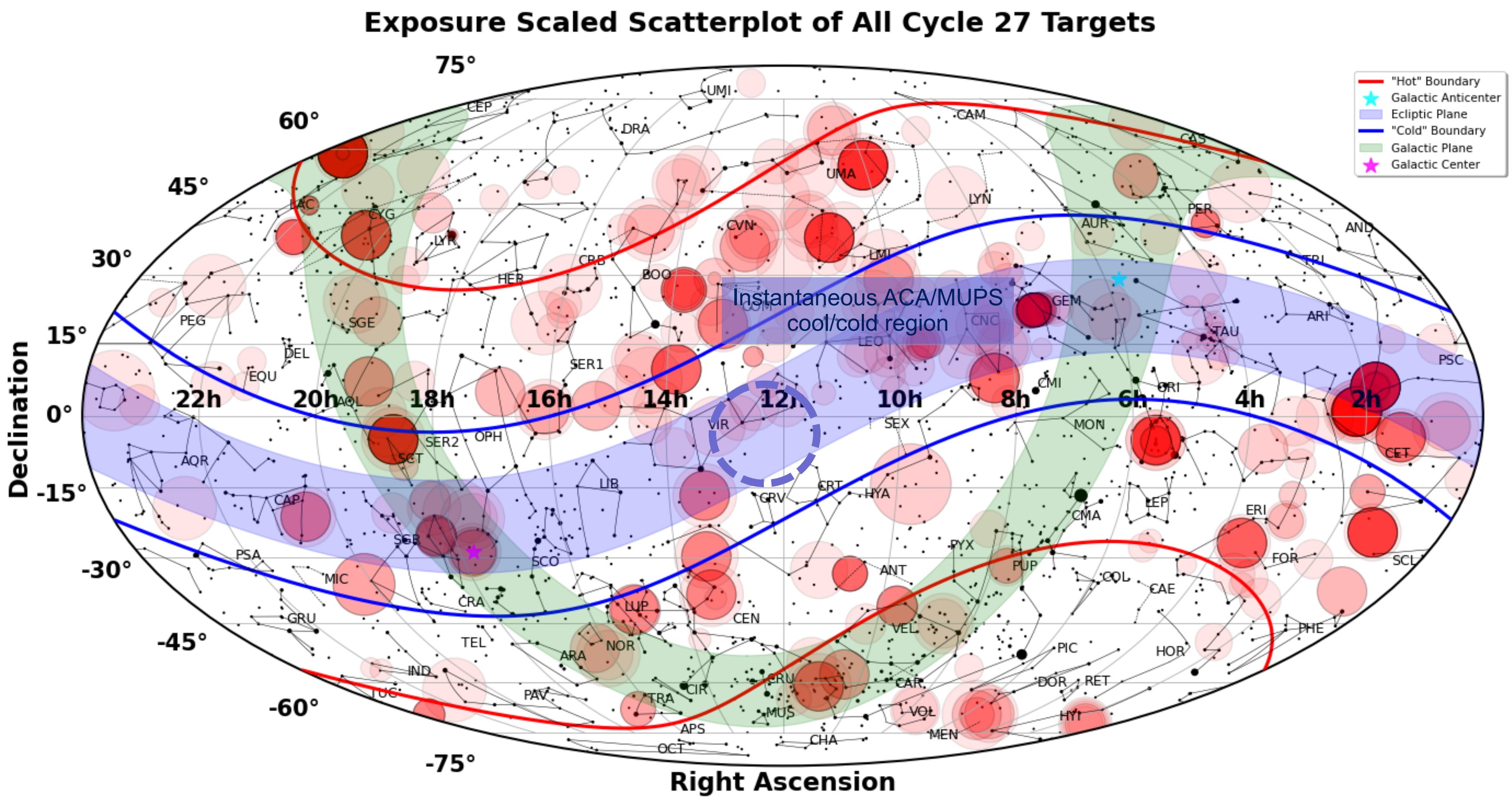


Resource Cost (RC) values for observing programs from *Chandra* Cycles 14-27. Starred targets have science observing constraints, circles are unconstrained.

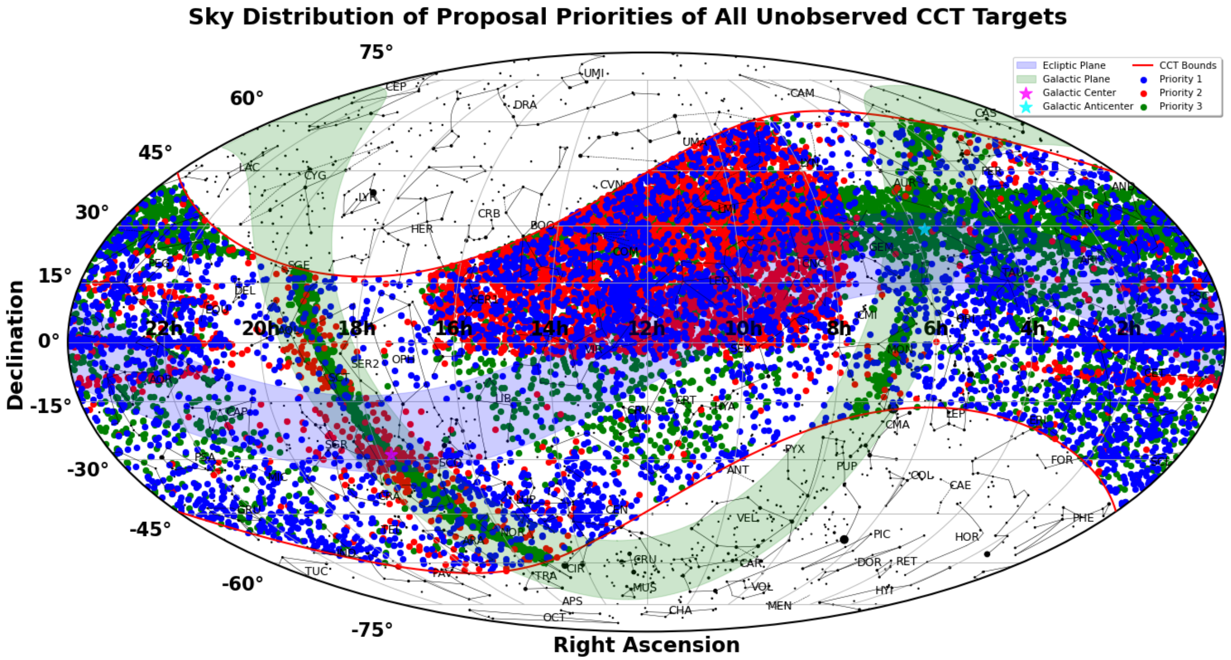
- Introduced in cycle 22.
- Replaces "constraint categories" (easy/average/difficult) used in previous cycles.
- Calculated for all non-TOO targets.
- On current (arbitrary) scale, peer review assigns total cost ~27,000.
- For Cycle 27: minor fixes, and pitch weighting changes to not as strongly disfavor HEL targets.

- Prototype resource-cost-like scoring for TOOs continues.
  - Currently only the number of triggers by category are tracked, so a fast 100 ks TOO is equivalent to a fast 1 ks TOO.
  - Prototype already useful in highlighting difficult or infeasible TOO proposals

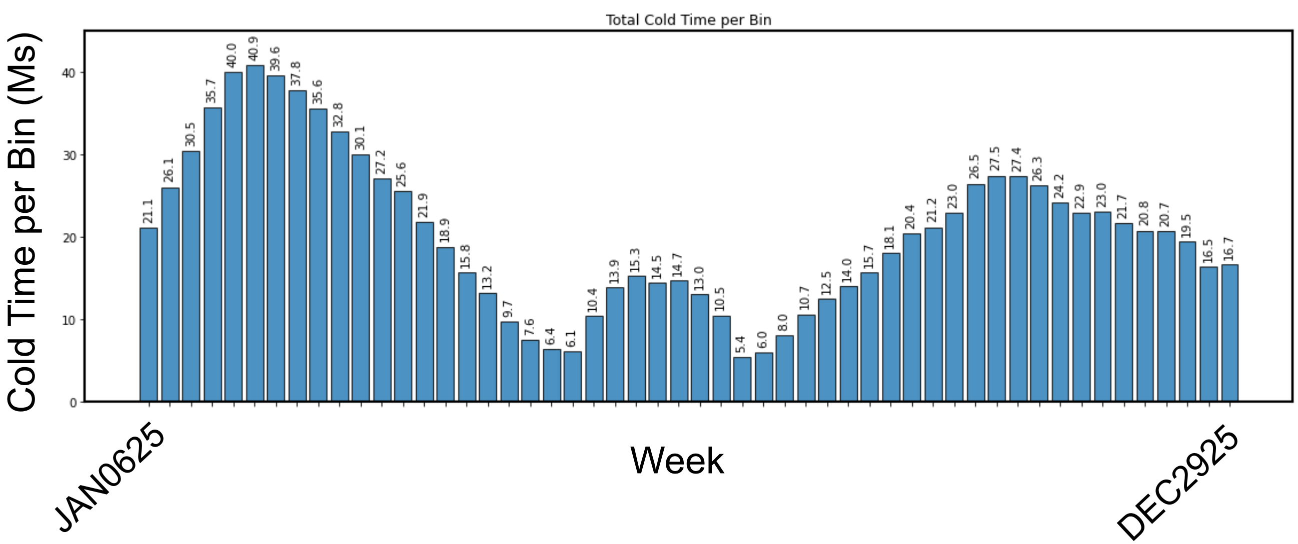
Target Distributions



Chandra Cool Targets (CCTs)

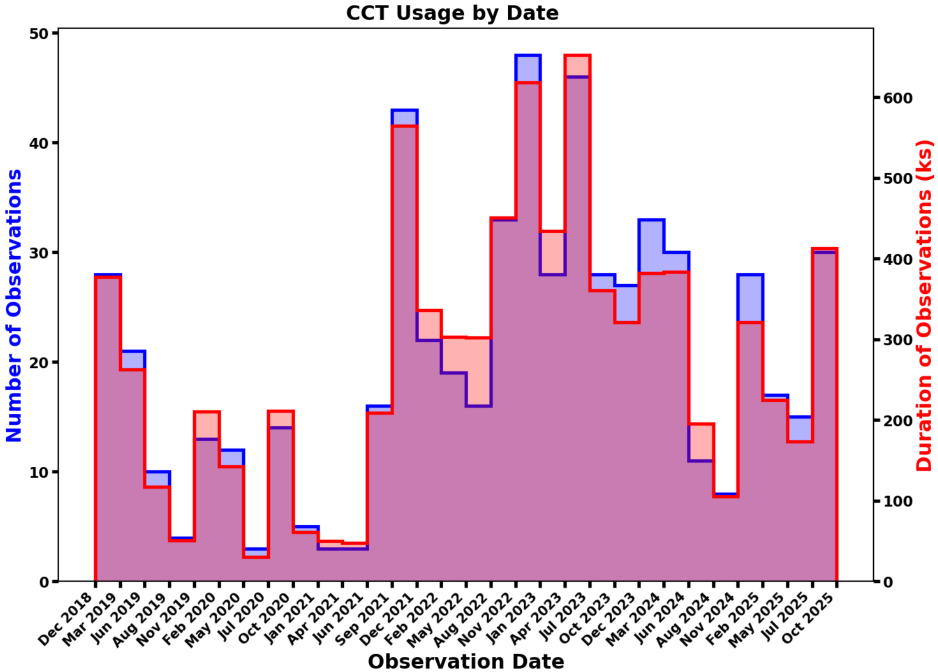


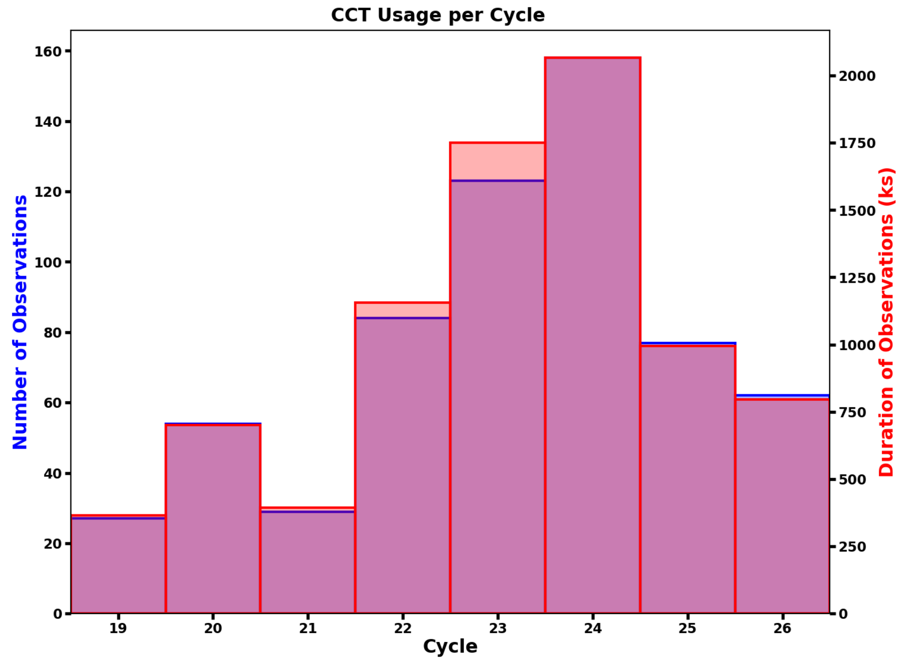
- Implemented in 2019
- 22 programs: galaxy clusters, ULXs, quasars, AGN, HMXBs, CVs, SFRs, cool stars, survey counterparts, radio galaxies, star clusters, Fermi sources, dwarf galaxies, symbiotic stars
- 10 ks ≤ t ≤ 35 ks; |b| < 40º
- ~19,000 targets, ~397 Ms, with 5Ms conflicted (~384 Ms remaining)



Adequate remaining cooling time in any week

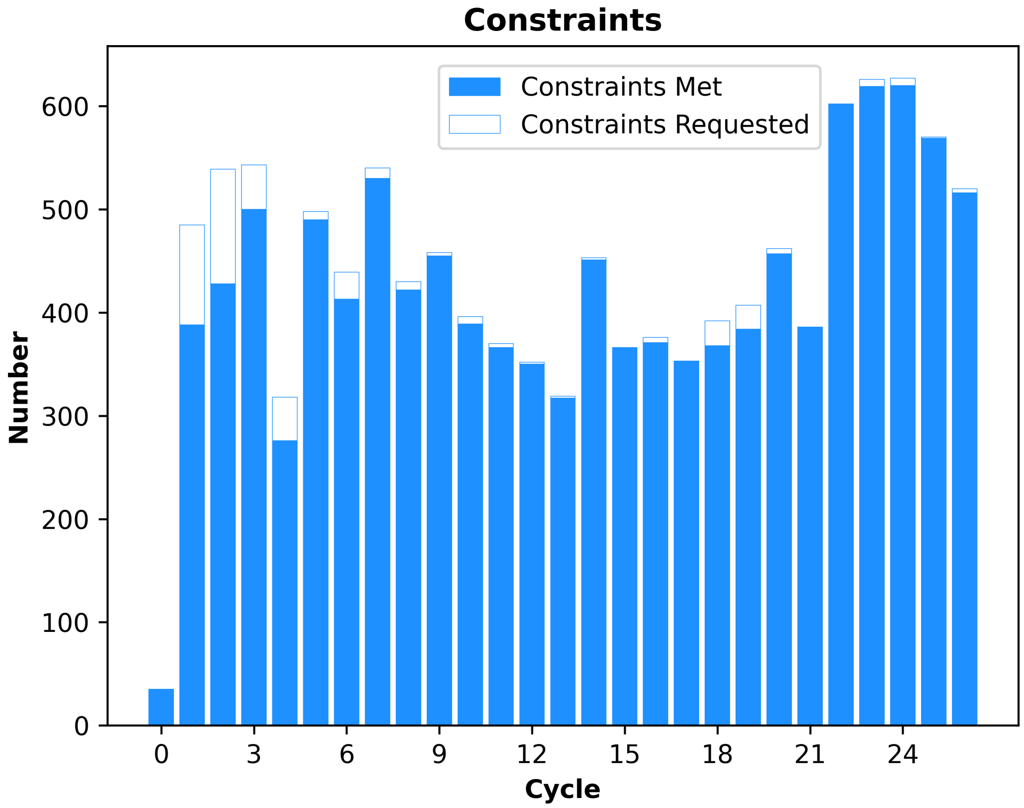
Chandra Cool Targets (CCTs)





CCT usage “spike” in Cycles 22 - 24, likely driven by recovery from operational events (e.g., HRC power anomaly, IU reset, Fine Sun Sensor issue), and by large programs with particularly difficult star fields observed prior to the ACA flight software patch

Science Constraints

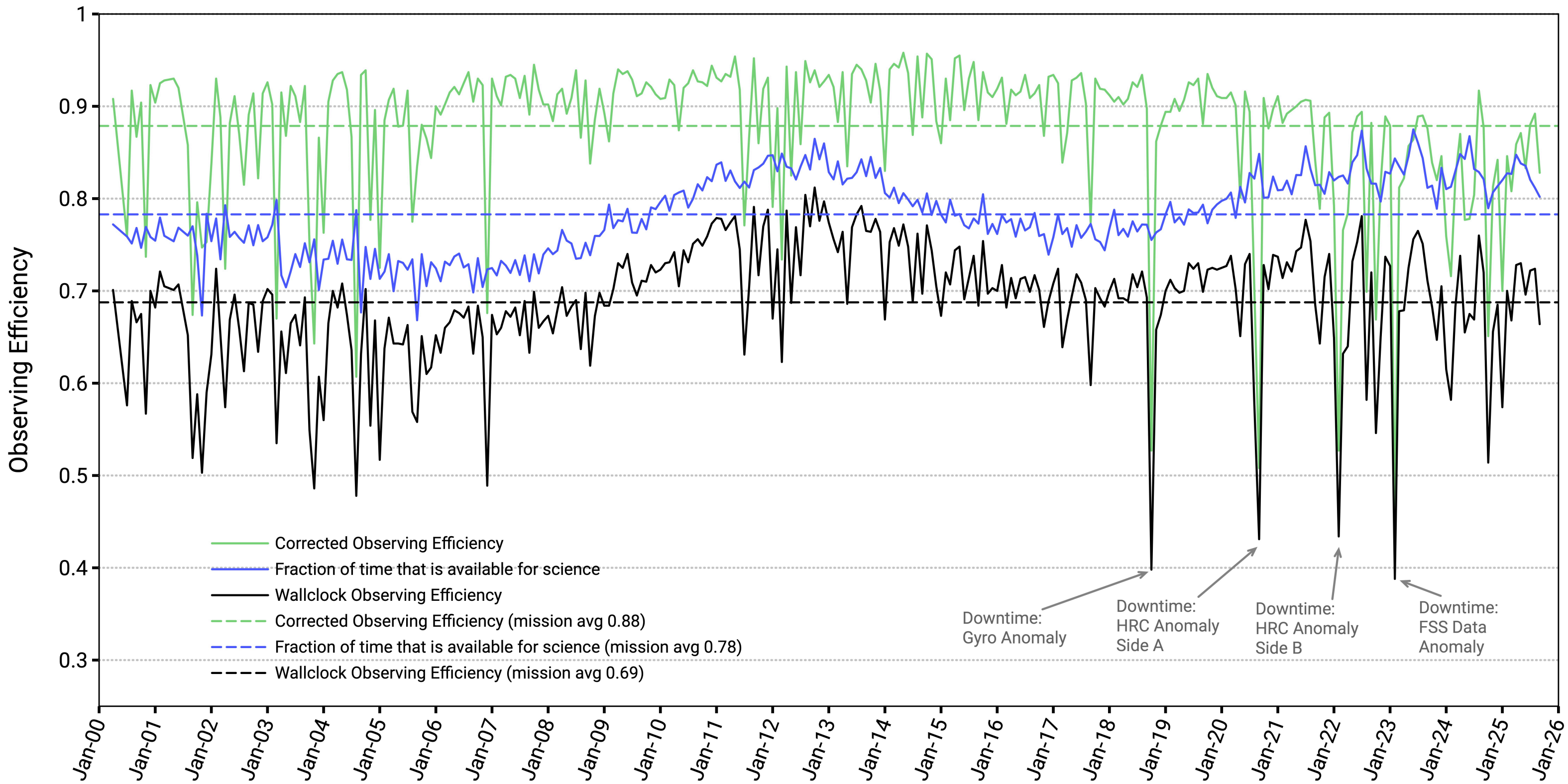


- Difficulty associated with meeting constraints is increasing due to spacecraft thermal limitations (e.g., decrease in maximum dwell times, increasing number of star field constrained targets).

- However, we continue to meet approved observing constraints successfully.

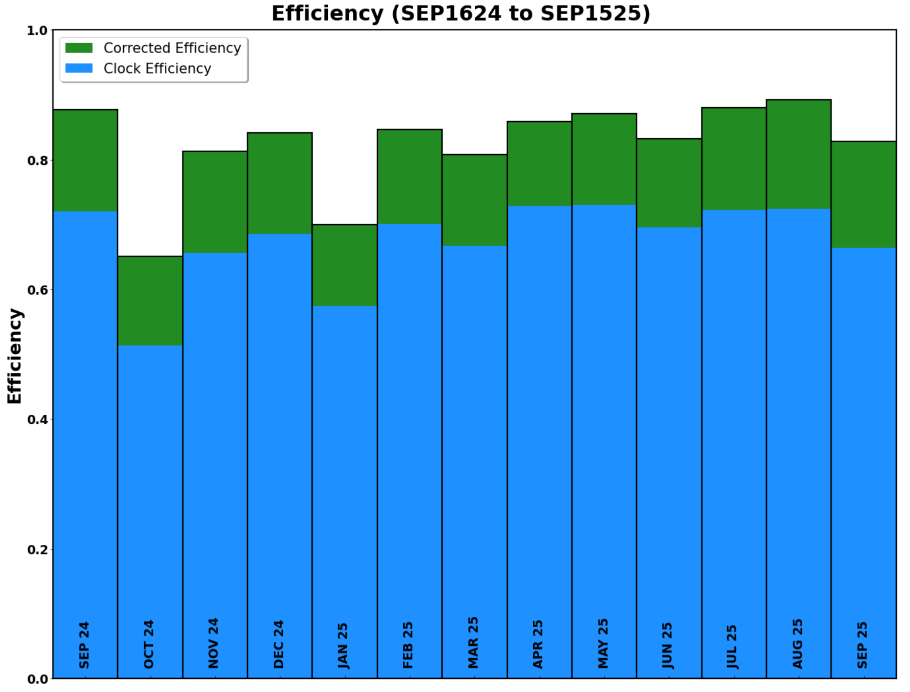
- Most missed constraints are due to solar flares and other operational events that lead to schedule interruptions.

Mission Efficiency History

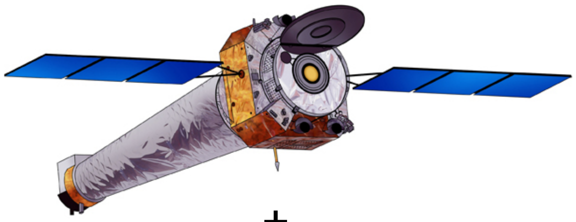


- The “corrected efficiency” (the fraction of available science time we spend observing, green line) has dropped somewhat in recent years. This is largely driven by shorter observation durations (which means more maneuver time), and the use of “intermediate attitudes” to help mange thermal issues.
- Nonetheless, the corrected efficiency remains high, and on par with historical values.

Observation Scheduling



Coordinated Observations



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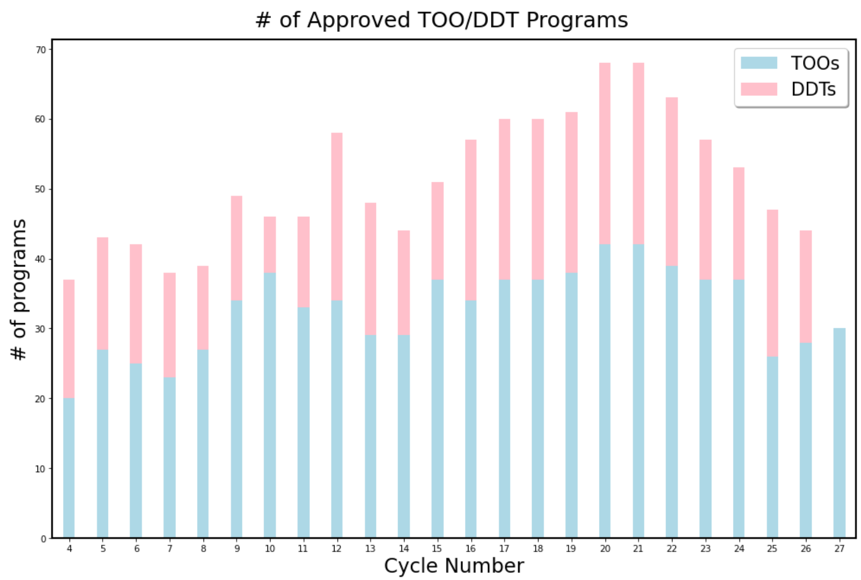
JWST, HST, NuSTAR, Swift, XMM, IXPE, NICER, VLA, ALMA, EHT

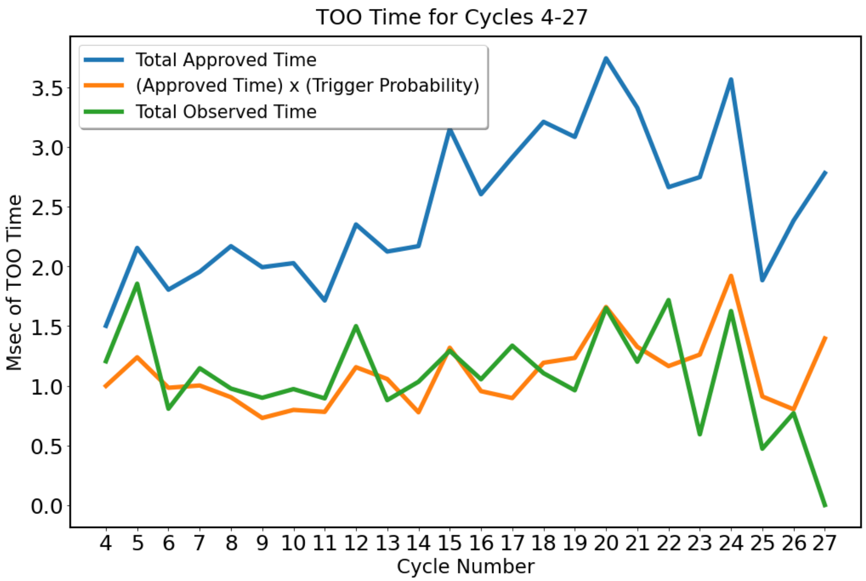
From Sep. 16, 2024 - Sep. 15, 2025:

- Scheduled: 1415 observations (21.3 Ms)
- Executed:
  - 35 TOO observations (690 ks)
  - 35 DDT observations (618 ks)
    - ✧ interrupted 6 operating loads for TOO/DDT support

- Chandra Coordinations (Sep. 16 2024 - Sep. 15 2025):
  - 66 observations for 1.24 Ms

TOO/DDT Observations: Historical Performance





Historical TOO/DDT performance has been very steady despite evolving thermal constraints.

- 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

Future Issues

- We have begun tracking a new thermal component for the fine sun sensor (FSS). Currently not a limiting factor, but likely to become limiting in the next year or so.
- The tank model has very recently become the limiting factor in a narrow range of pitch angles. We have one more limit increase before we hit the caution limit. Potentially raising the limit higher would require detailed investigation.
- Continuing to track ObsID usage. We're likely to "run out" of ObsIDs as early as 2030 (worst case). Will need to investigate solutions starting a few years prior to this.
- HRC investigation and recovery, with scheduling adjustments.
- Further updates for public-facing data to further support the ACROSS initiative (e.g., JSON)
- Make the TOO RCC official?

Summary

- The overall temperature increase of Chandra continues to limit the amount of time we can observe at any given solar pitch angle, due to the temperature limits of the various components.
- This complicates both constructing the Long Term Schedule and detailed weekly planning, e.g., due to component temperature limits, and increases in the detection threshold of the aspect camera.
- The effects of this heating are mitigated, as much as possible, by several proactive software, procedure, and policy changes.
- Despite increasing challenges, observing metrics remain favorable, with observing efficiency, TOO/DDT response, and science constraint compliance that are on par with mission history.
- There are no known barriers to the continued successful and efficient operation of Chandra for years to come.

Backup Slides

Star Field Constrained Targets

- Increased aspect camera temperatures means a higher detection limit for guide stars
- Some star fields have become extremely difficult to do, with narrow yearly windows (roll angle ranges) when they are observable
- These “star field constrained” targets make up the majority of our most difficult programs to schedule
- The aspect camera flight software was patched in May 2023 to use new dynamic background algorithm, improving sensitivity for guide stars. The effect is equivalent to 1-1.5 degree cooling, a significant benefit for planning
- However, the problem will worsen over time, with some star fields expected to become unobservable in the near future

Tool/Process Updates

Star Field Checker Tool

- Star field checker webtool was released for AO 25
- Fewer proposals with difficult star fields were submitted
- Processing time and memory usage per target is non-negligible, raising issues if large numbers of targets submitted at once (e.g., if incorporated in CPS and many proposers use it just before deadline)
- Queueing system, target list input, and inclusion in CPS all in development for next year

Tool/Process/Limit Updates

TFTE Heater Set-point Change

- It was realized that lowering the set-point temperature for the Telescope Forward Thermal Enclosure (TFTE) heater provided unexpected thermal relief for the ACA.
- New set-point temperature was quickly implemented
- This likely "recovered" 1-2 years worth or nominal ACA heating

Tool/Process/Limit Updates

ACIS Heater Set-point Investigation

- ACIS investigated 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.
- After a detailed investigation, it was determined that exploratory observations would be required to answer this question definitively
- Unfortunately, this study found that lowering the ACIS set-point temperature did not significantly improve subsequent max-dwell capabilities

Tool/Process/Limit Updates

- History of recent thermal limit changes

Model	Date of most recent update	Planning limit relaxations in past year
ACA	2022 Feb	- 5.8 C -> -5.2 C
MUPS	2020 Apr	210 F Limit Unchanged
OBA	2022 Jan	Non-LETG Limit unchanged 103 F Separate LETG limit 102 F
Tank	2021 Oct	115F -> 120 F
PLINE	2020 May	50 F Limit Unchanged
DEA	2022 May	37.5C -> 38.5 C
ACIS FP	2022 Nov	ACIS-I: -112C -> -109 C* ACIS-S: -111C -> -109 C* *when calibration allows

Sample of Significant Planning Efforts

Completed in Cycle 23:

- Sgr A* - 100 ks, including
  - Tightly coordinated with the EHT
- Galactic Center mosaic - 1.7 Msec; CMZ Molecular Cloud - 900 ks
  - 2.6 Msec all in the same part of the sky (same “good” and “bad” pitch windows)
- Abell 2029 - 150 ks
  - Extremely difficult star field
  - No workable "first order" solution, at any temperature. Required special consultation with the ACA team.
  - Ultimately led to very tight observing windows with extra ACA cooling.
- QSO J0041-4936 - 150ks; PSZ2G358.98-67.26 - 4.9 ks; 2MASX J15114125+0518089 - 60 ks
  - All severely star field constrained, difficult to schedule, with short allowable windows
- B1152+199 - 50 ks
  - 5 x 10 ks, monitor series with a monthly cadence that also has a difficult star field.

Sample of Significant Planning Efforts

<u>Coming Up in Cycle 24:</u>

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

•Abell 2029 - 275 ks; SIG A2029 - 170ks:
  - Extremely difficult star field

• QSO J0041-4936 500ks; MCXCJ0216.3-4816 - 25ks; SDSS J114907.15+004104.3 - 3.1ks
  - All severely star field constrained, difficult to schedule, with short allowable windows

• Some likely challenging approved Cycle 24 TOO programs

Note that the story regarding the toughest programs to schedule has largely become about “star field constrained” targets

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.

TOO/DDT Observations: Planning Impacts

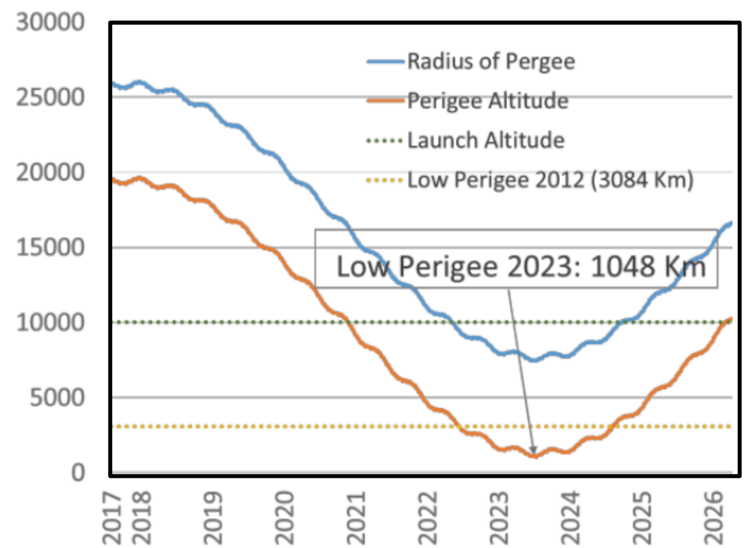
Snapshot of Planning Process

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)					

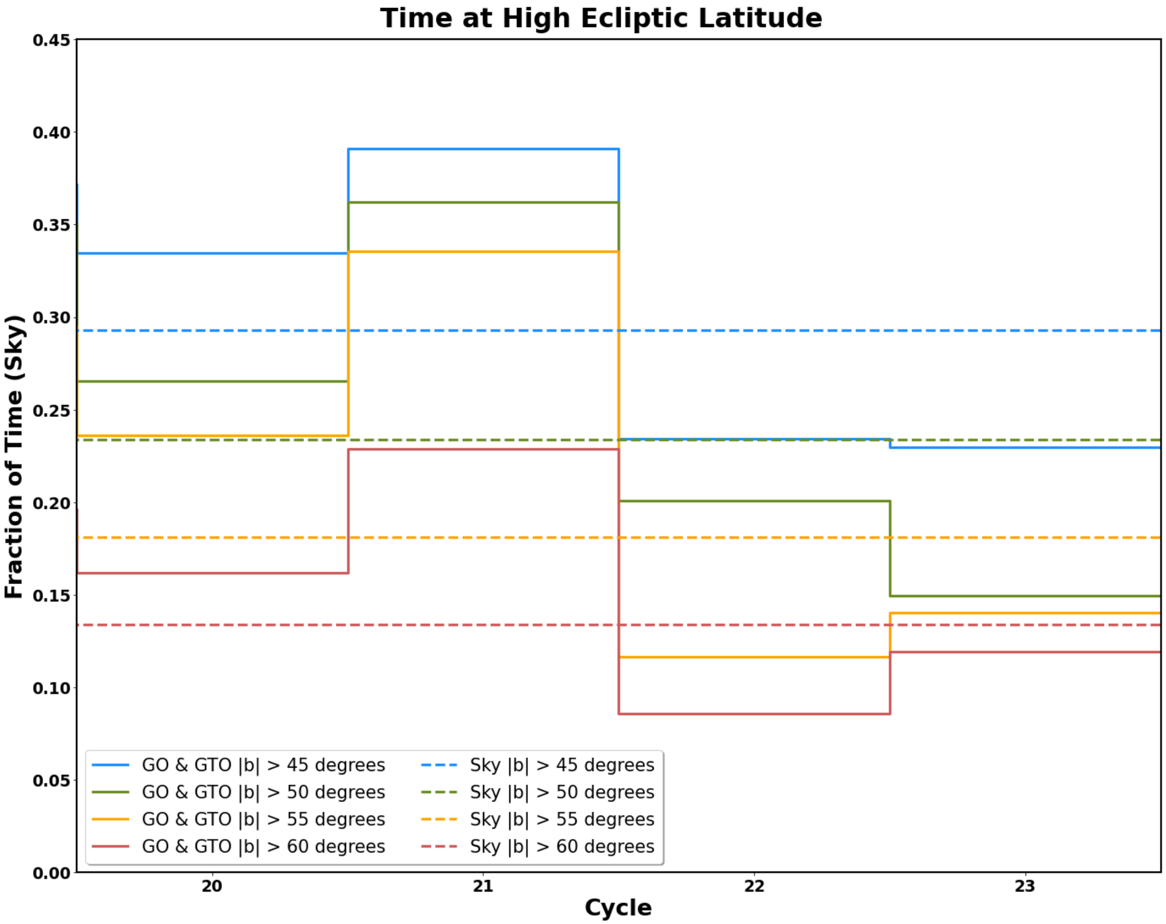
Tool/Process/Limit Updates

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.



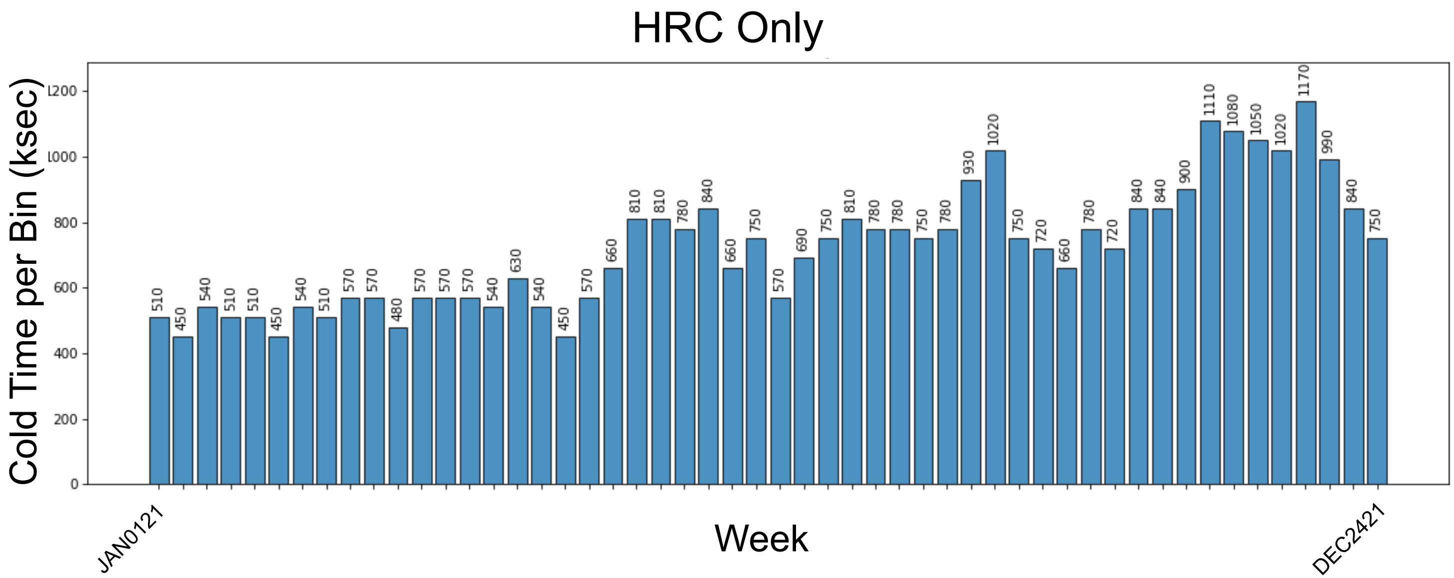
Target Distribution: Cycle 22



- 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>.

Chandra Cool Targets (CCTs)

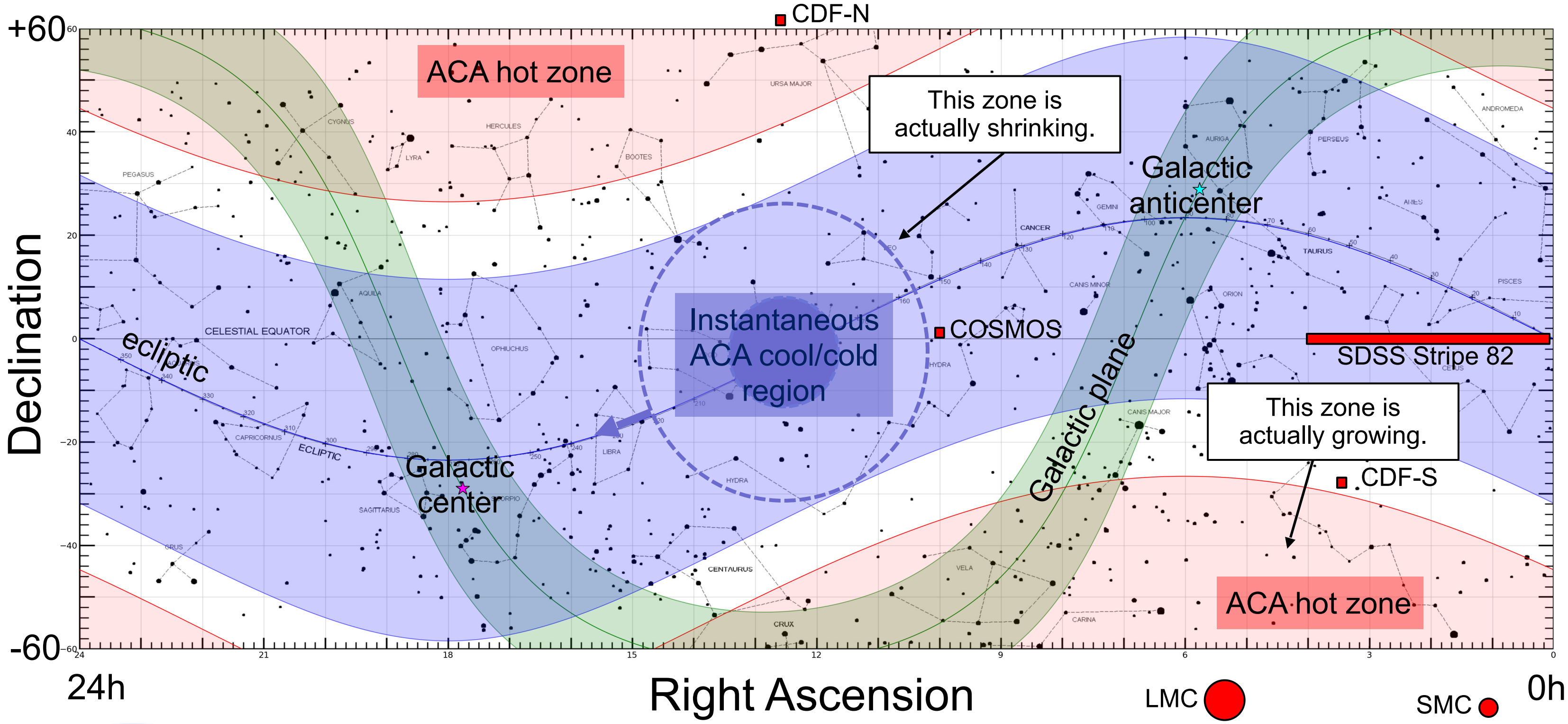


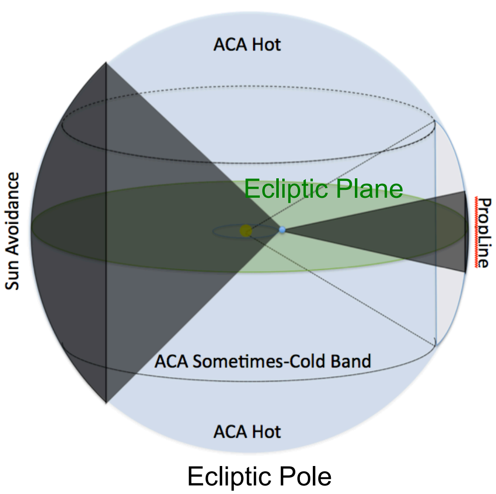
- Recall that cold HRC observations are particularly useful for thermal management, since ACIS is the main limiting factor at high pitch angles.

- 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: Sky View



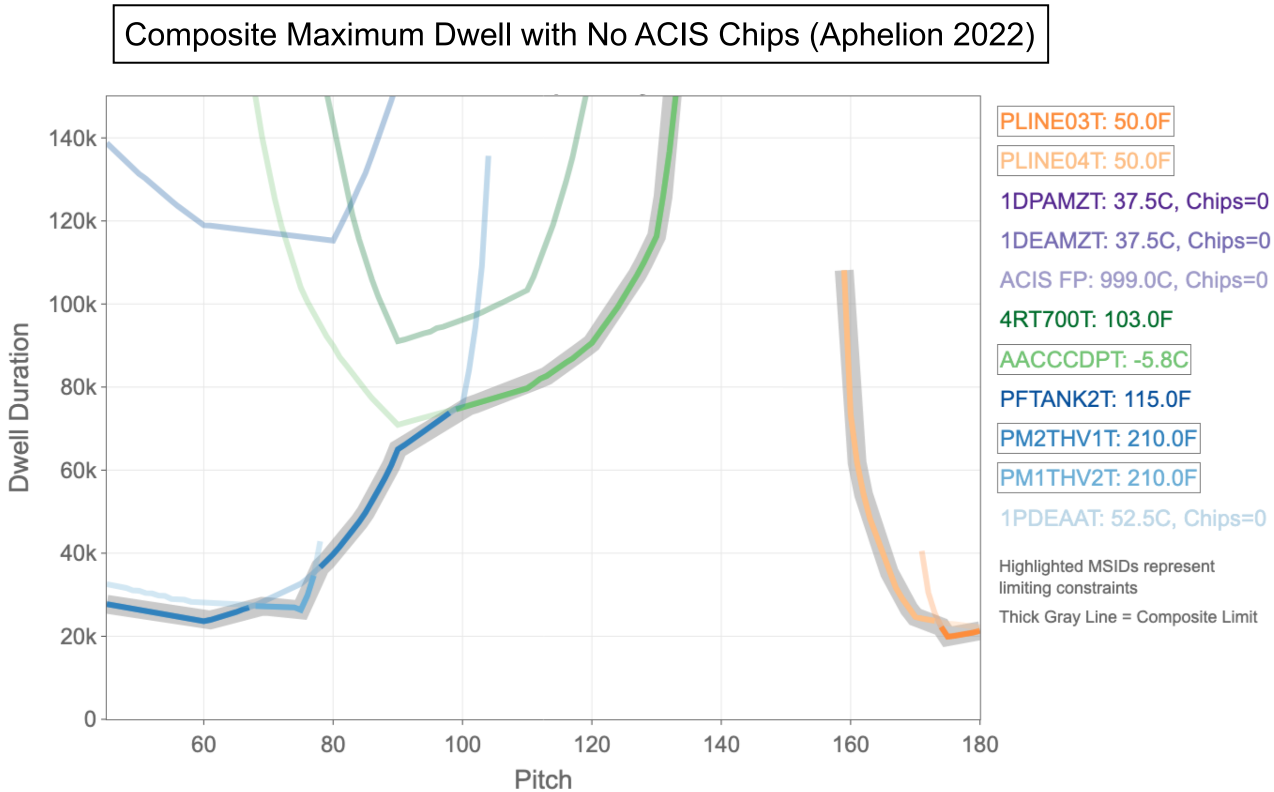


- Sometimes-cool/cold ACA (-Z) region covers large sky area.

  - Many well-known fields can provide some cooling; others always heat the ACA.

  - The cool regions are shrinking and the hot ones are growing.

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.