Mission Planning Updates

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On behalf of SOTMP:
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Overall Context for Mission Planning

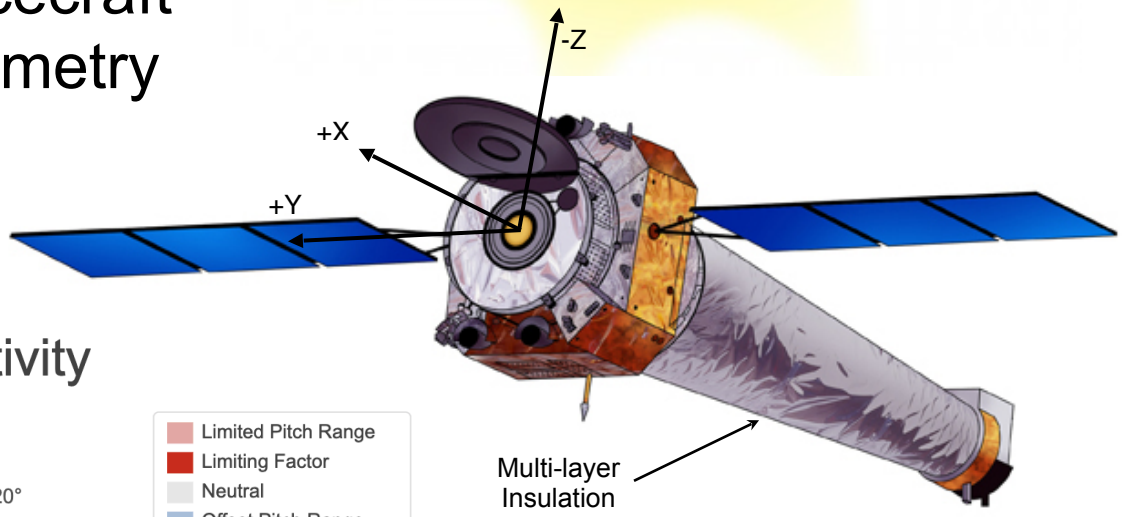
Goal:
Maximizing the science return of the mission in the presence of constraints:

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

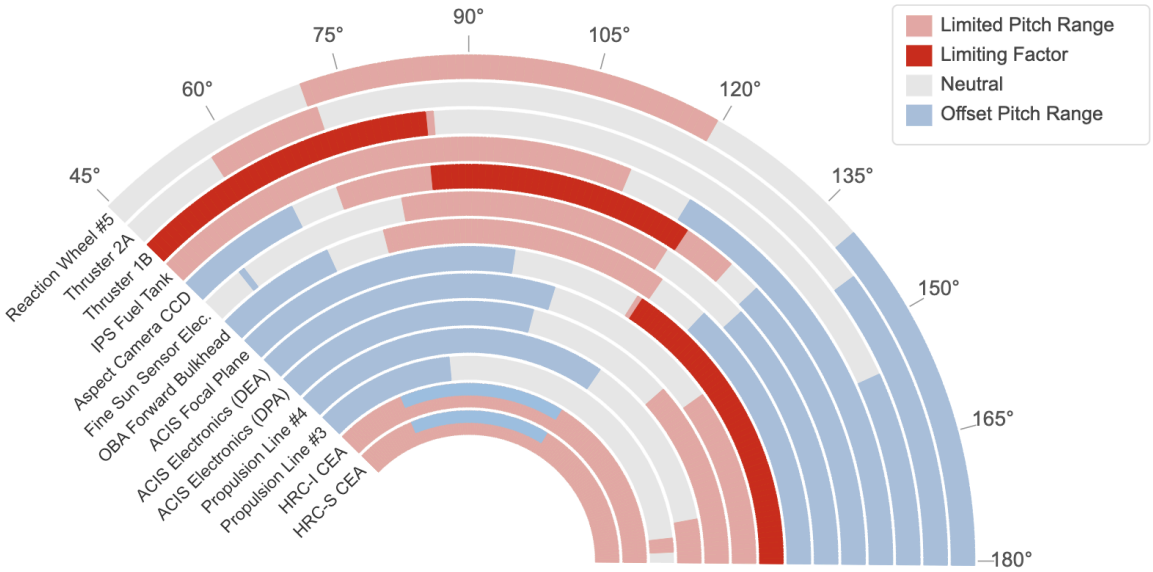
Engineering constraints, e.g.,
- *thermal constraints*
- star field constraints
- momentum management
- Sun, Moon, Earth, bright X-ray source avoidance

Chandra Thermal Restrictions

Spacecraft Geometry

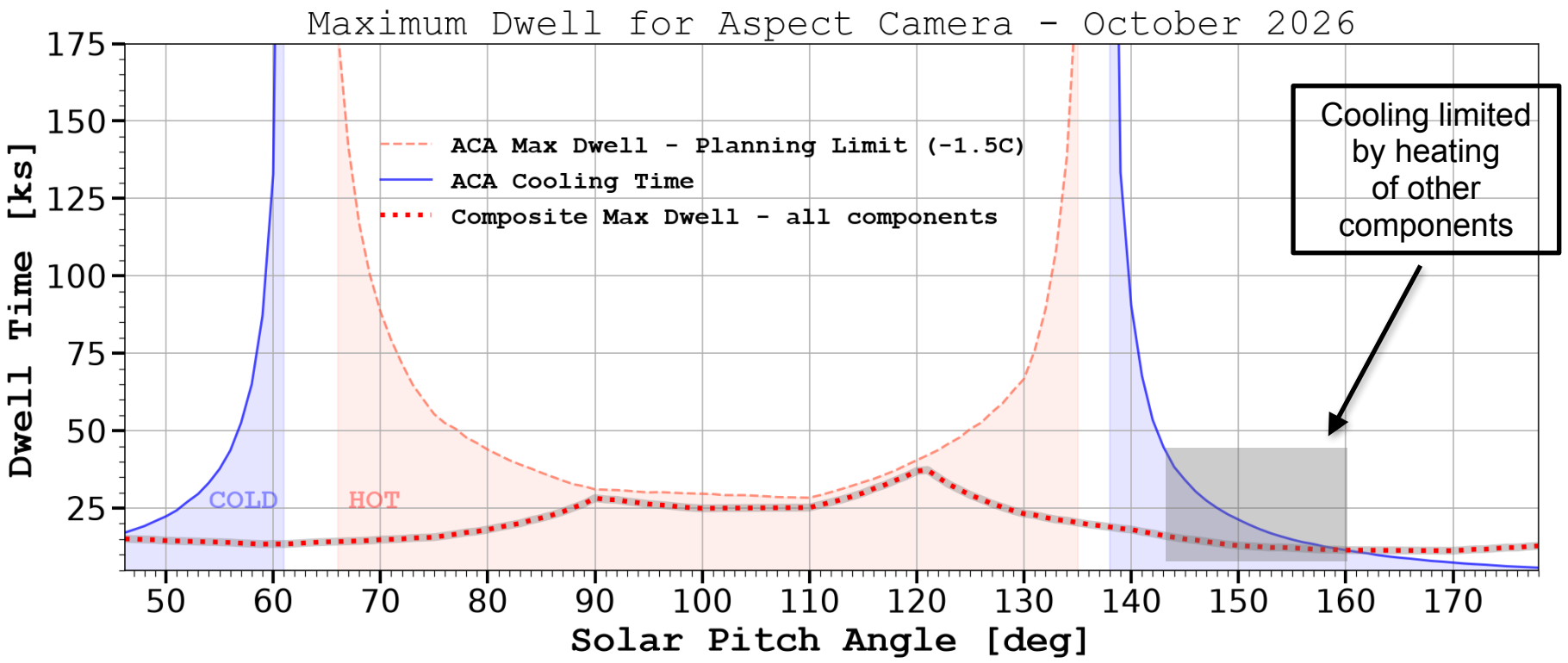


Constraint Pitch Sensitivity



Thermal Restrictions

Thermal Balance: A Summary

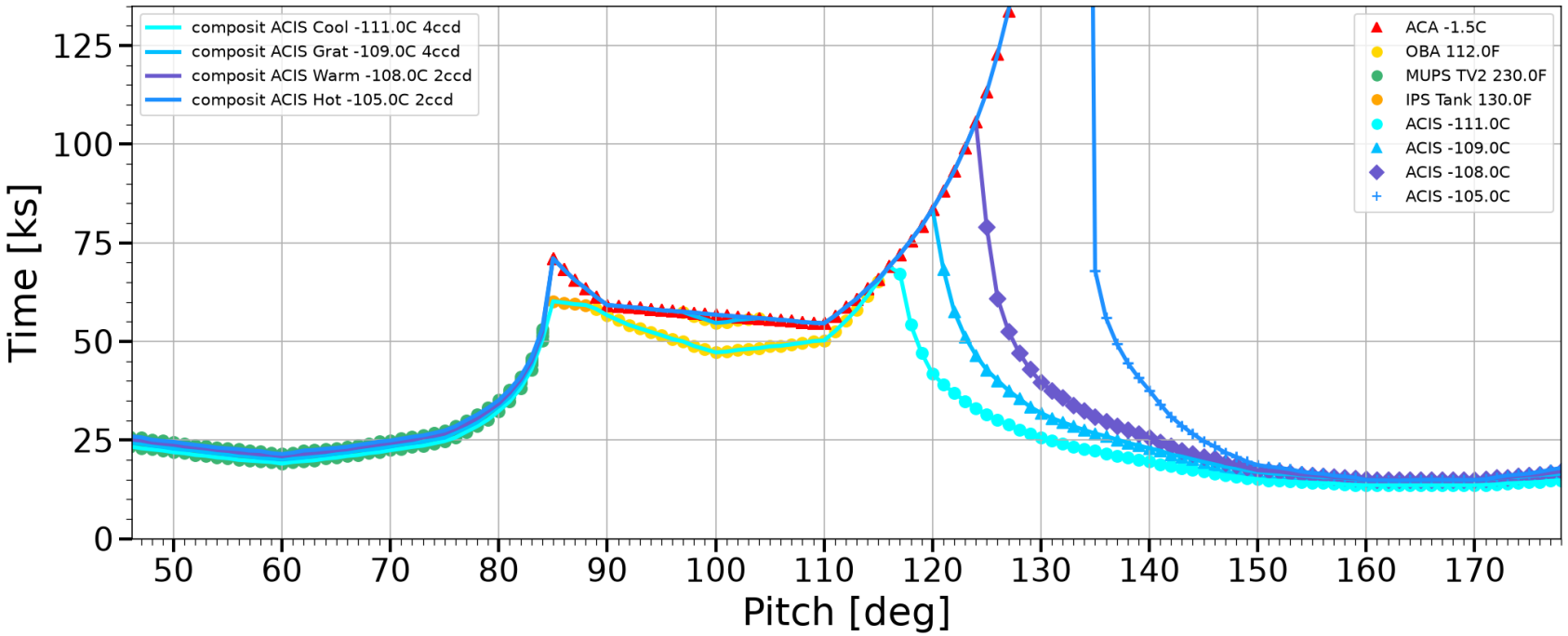


Red: maximum exposure before exceeding temperature limit (dotted is **composite** for all components).

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

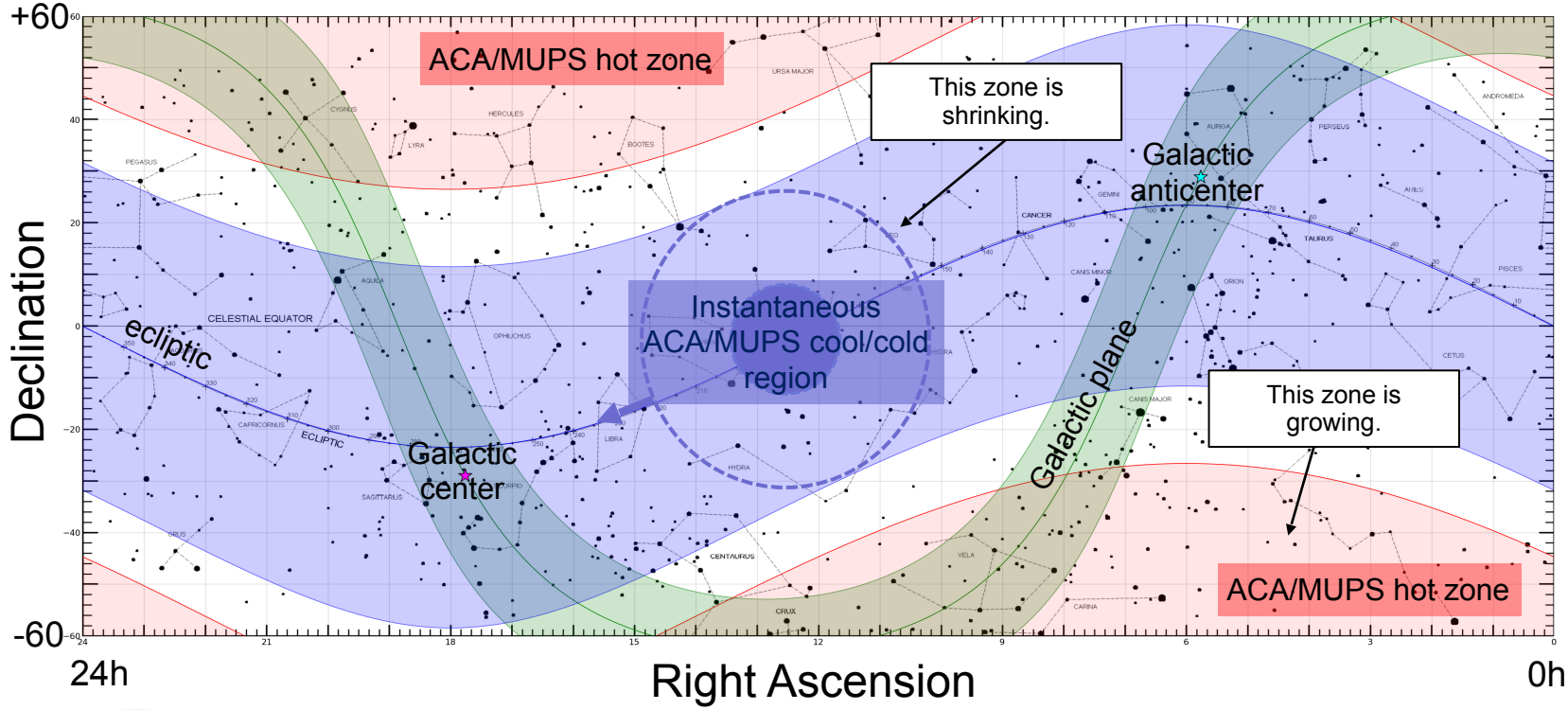
Thermal Balance: A Summary

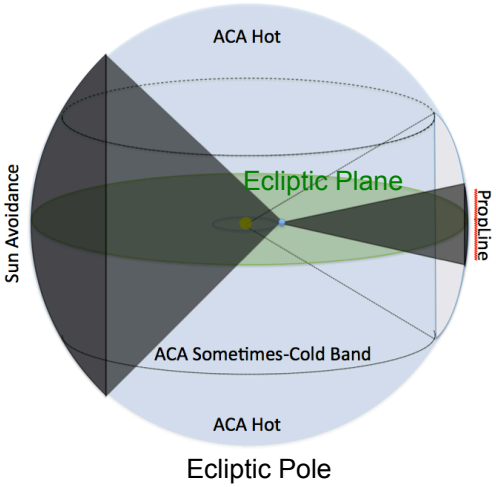
Composite Maximum Dwell for July 2026



- 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: 4.49d, used 3.97d = 88.42% 02-Nov-2026 00h to 09-Nov-2026 00h (UT) antisun plot skybal plot

#Orbits: 3 Orbit Time: 388.46ks LTS Time: 343.00ks HRC Time: 0.00ks skybal: -65.70 #Targets: 10

Thermal Budget: cold budget
aca : +57.0
mups : +36.8
ipstank : +94.4
dpa : +30.7
hrc : +114.5

momentum axes
P_x : -0.05
P_y : -1.03
P_z : +9.27

momentum totals
P_tot : 9.33
P_bal : -5.67

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
402712	33258	SS 433	25.0	287.957	4.983	286.9 290.5	73.3 67.1	ACIS-S	6	2	HETG	Marshall	GTO	28	0	N	Y	N	N	N	N	Y	N	N	-109.0
402714	32585	SS433	25.0	287.957	4.983	286.9 290.5	73.3 67.1	ACIS-S	6	2	HETG	Marra	GO	28	0	N	N	N	N	N	N	N	Y	Y	-109.0
503602	H 31579	Cassiopeia A	30.0	350.867	58.820	237.2 245.6	124.4 123.1	ACIS-S	2	0	NONE	Patnaude	GO	27	0	N	N	N	N	N	N	N	N	N	-111.0
503609	31131	IRAS 00500+6713	39.0	13.297	67.501	208.0 216.5	124.9 125.6	ACIS-I	4	0	NONE	Suzuki	GO	27	0	N	N	N	N	Y	N	N	N	N	-105.0
503644	H 31598	Kes 73	40.0	280.333	-4.936	283.8 286.8	63.3 56.7	ACIS-S	2	0	NONE	Temim	GO	27	0	N	N	N	N	N	N	N	N	N	-111.0
705386	31239	BOSS0210W	50.0	32.750	0.780	344.4 326.6	165.7 160.8	ACIS-I	4	0	NONE	Lepore	GO	27	0	2.0	N	N	N	N	N	N	N	N	-105.0
705402	H 31693	SDSS J014837.63+0600	30.0	27.157	6.006	313.1 304.9	167.3 160.6	ACIS-I	4	0	NONE	Connor	GO	27	0	N	N	N	N	N	N	N	N	N	-105.0
705409	31262	CHQ J0210+0050	40.0	32.500	0.840	343.4 325.9	165.7 160.7	ACIS-I	6	2	NONE	Liang	GO	27	0	-1.1	N	N	N	N	N	N	N	N	-105.0
705423	31276	3CR 415.2	34.0	308.192	53.764	277.6 284.3	102.6 100.2	ACIS-S	4	2	NONE	Massaro	GO	27	0	N	N	N	N	N	N	N	N	N	-105.0
705460	31709	MACHO 79.5505.178	30.0	78.640	-68.915	40.3 33.3	91.4 90.8	ACIS-S	2	0	NONE	Han	GO	27	0	N	N	N	N	N	N	N	N	N	-105.0

Cycle

Star field

Constraints

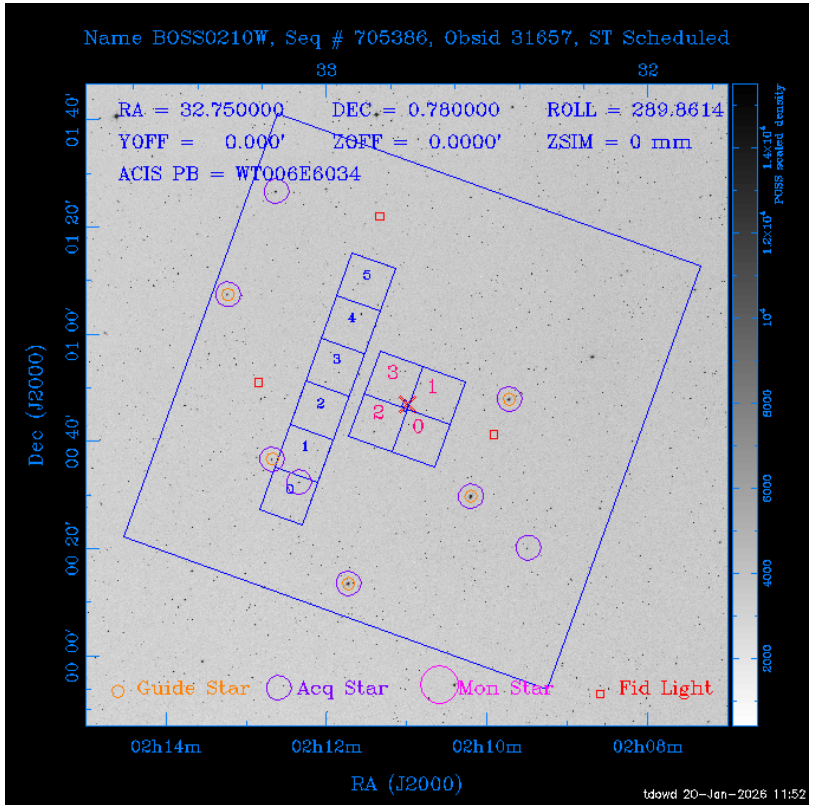
Coordinations

- 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.
- Construction of the Cycle 28 LTS was completed in October, taking several weeks versus several months prior to the auto-scheduler.

Tool / Process Updates

“Nudging” software for difficult star fields

- Aspect camera’s detection threshold rises with time as the detector heats, leaving fewer stars that are suitable for acquisition and guiding.
- Fields with fewer stars are difficult to do, often requiring that we cool the ACA below the planning limit and/or schedule the observation at a specific time of the year.
- Some fields can be improved with small pointing changes that won’t impact science. We now test all star constrained observations for this case.
- For identified cases, USINT will work with the observer to confirm that a small pointing change is acceptable.



Tool / Process Updates

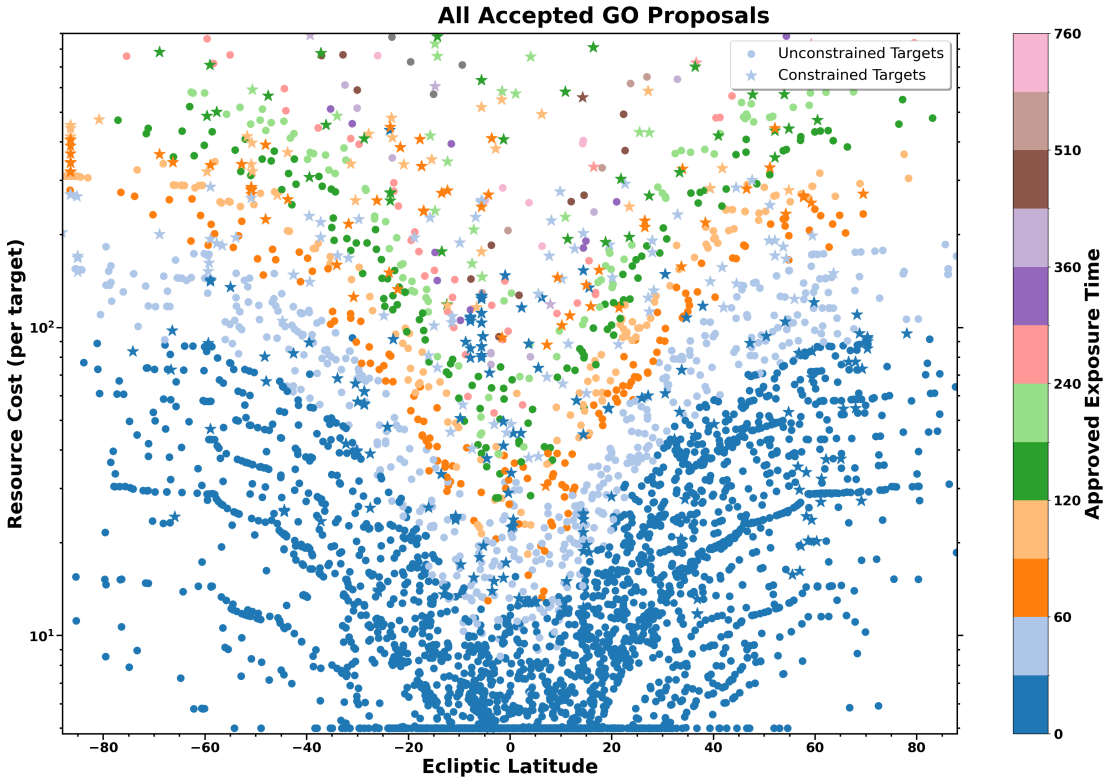
Working with the ACROSS Initiative

- The ACROSS Initiative aims to provide tools and resources to support the TDAMM science community.
- CXC work includes sharing observing constraints, posting Chandra ephemeris and radzone information, and validating visibility calculations.
- There will be a new webpage for “fast” TOOs/DDTs that posts and updates preliminary scheduling information as soon as it’s available, with an associated fidelity/confidence rating.
- This page will be available to the public, and is expected to go live in the near future.

HRC-S recovery activities

- The HRC-S anomaly (see HRC talk) significantly impacted long-term scheduling.
- Assuming continued successful operation, HRC-S observations will be prioritized in the LTS (likely requiring significant updates to the current LTS).

Resource Cost

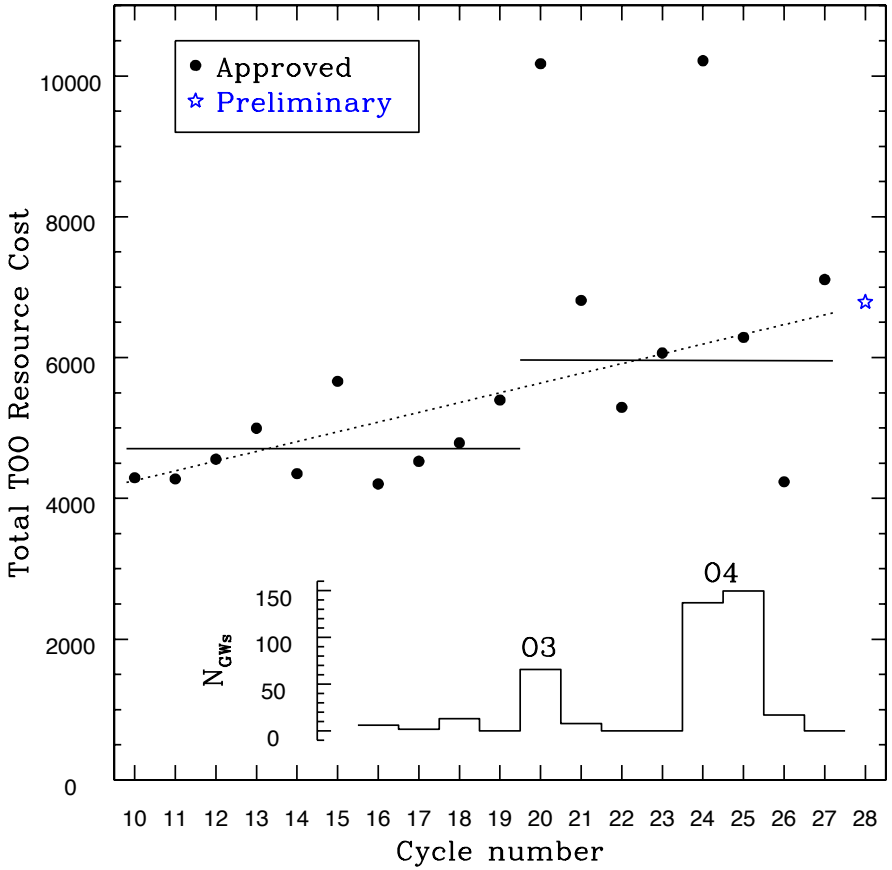


Resource Cost (RC) values for observing programs from *Chandra* Cycles 14-28.
Starred targets have science observing constraints, circles are unconstrained.

- 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 29: minor adjustments for pitch weighting.

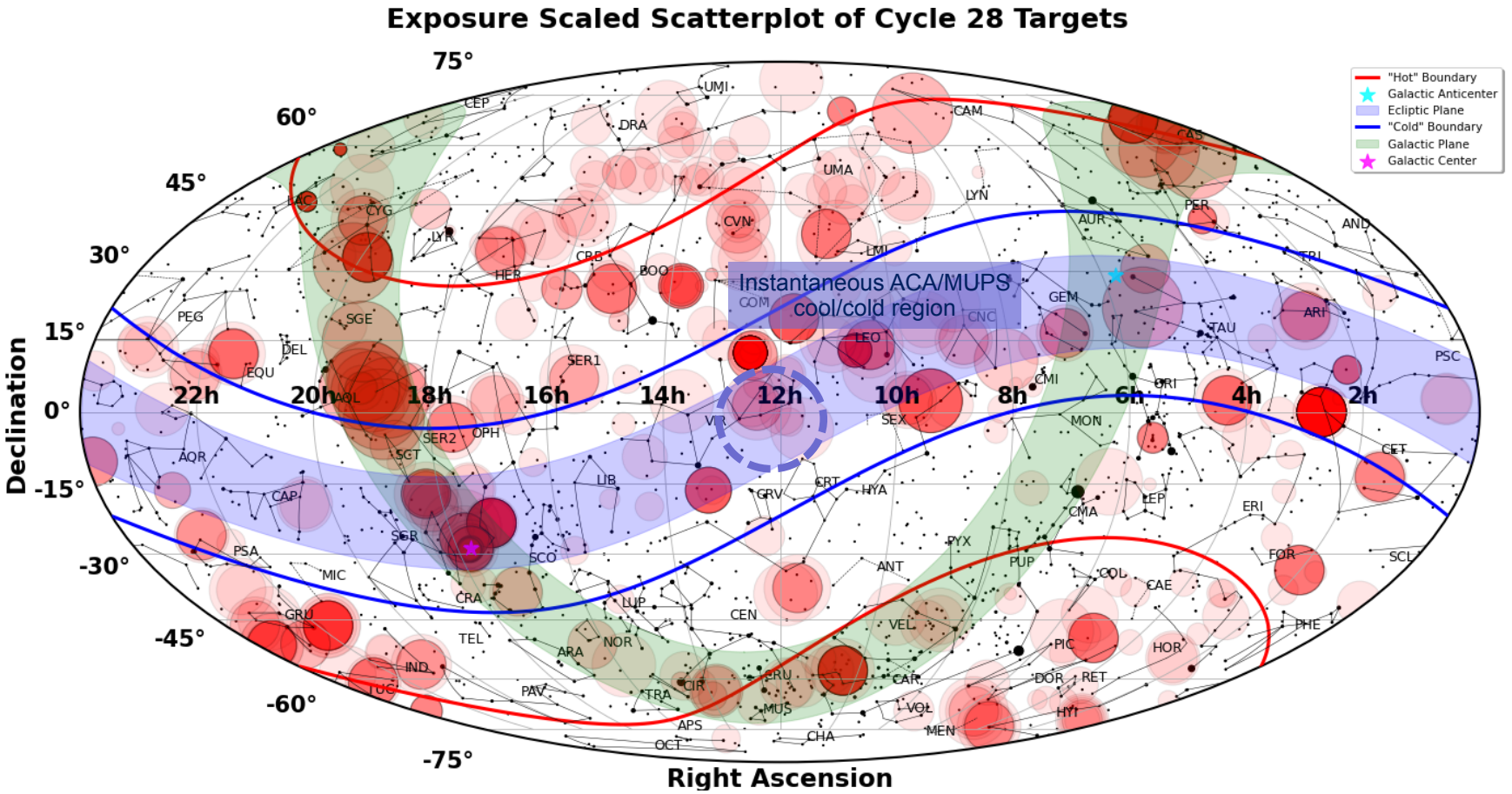
- Prototype resource-cost-like scoring for TOOs continues.
  - Currently only the number of triggers by category are tracked, so a fast 100 ks TOO is equivalent to a fast 1 ks TOO.
  - Remains useful in highlighting difficult or infeasible TOO proposals and tracking trends.

TOO Resource Cost

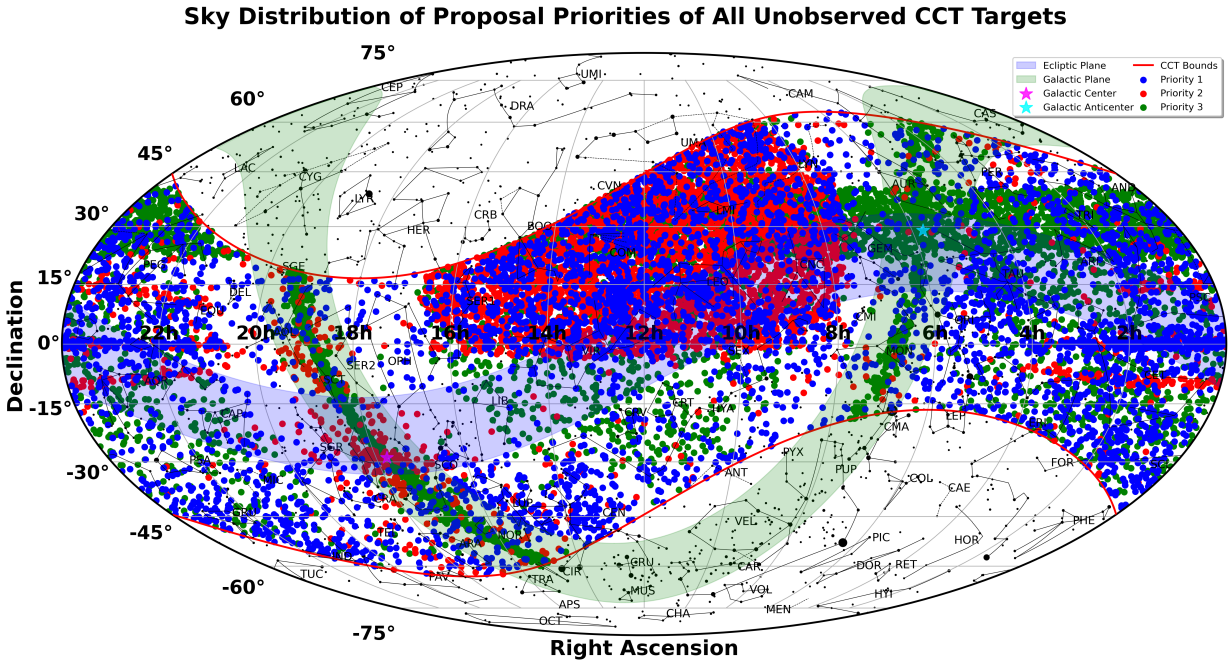


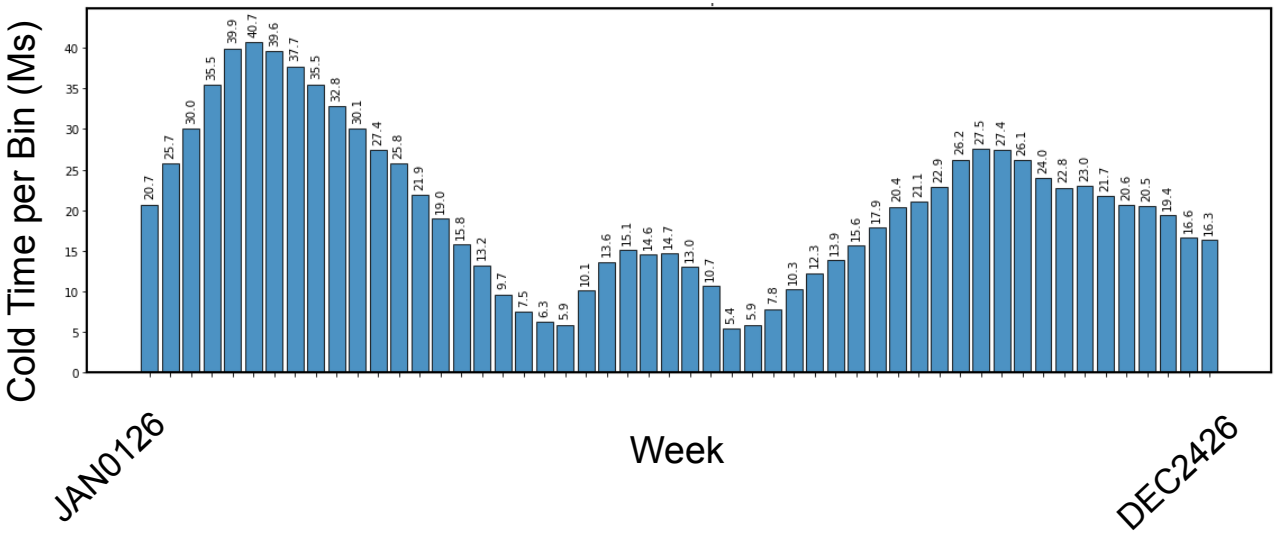
- Used the TOO RCC to investigate trends in the scheduling burden of TOOs.
- Analysis shows an uptick that may be driven by GW science (with significant scatter).
- Bootstrapping analysis indicates that this uptick is strongly statistically significant, even with conservative assumptions (e.g., removing outliers).
- No plans to officially implement the TOO RCC, partly due to issues associated with identifying the proper budget.

Target Distributions



Chandra Cool Targets (CCTs)



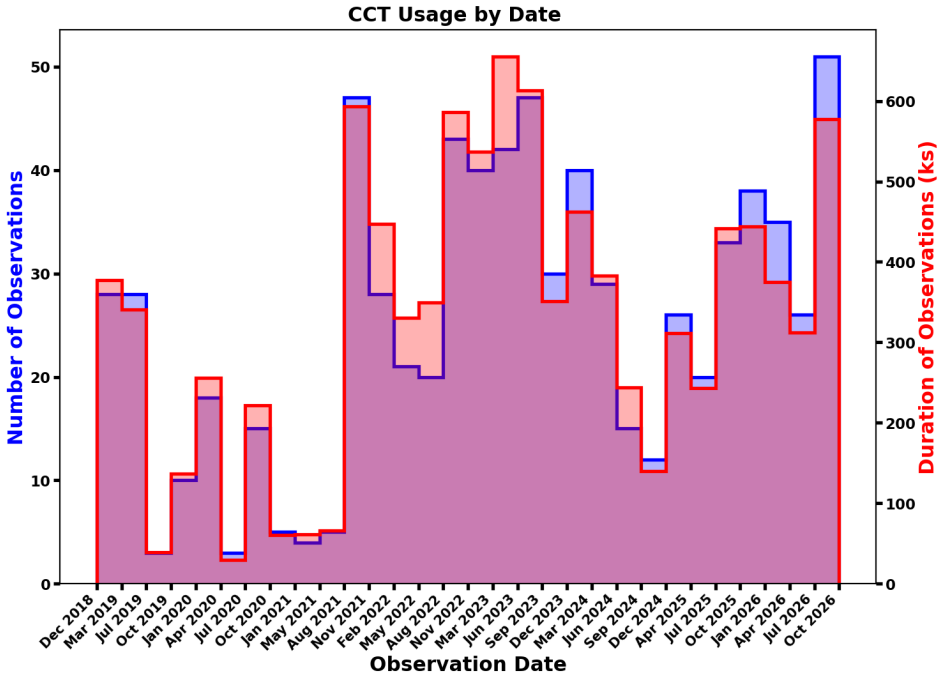


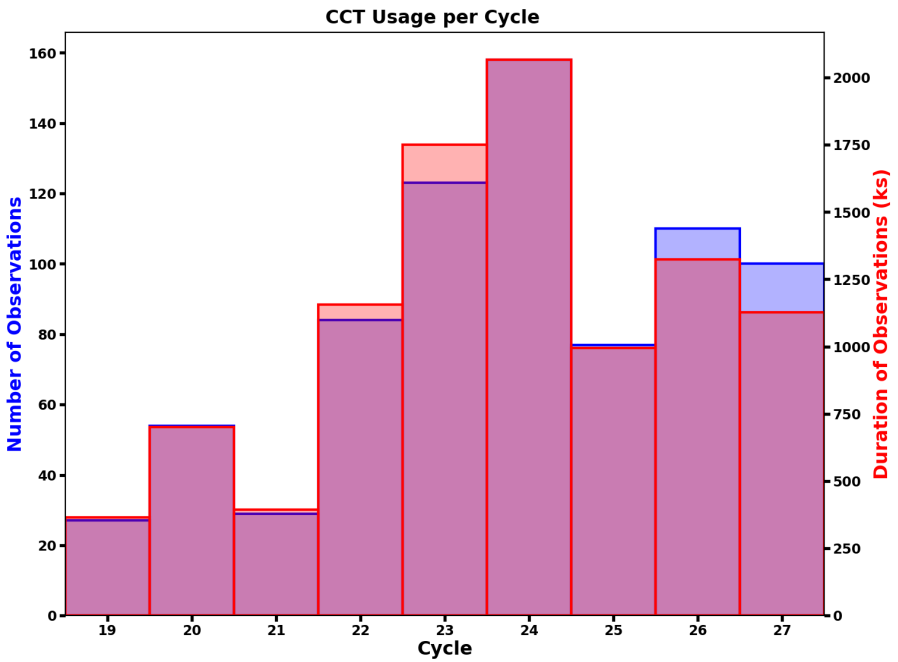
- Implemented in 2019
- 22 programs: galaxy clusters, ULXs, quasars, AGN, HMXBs, CVs, SFRs, cool stars, survey counterparts, radio galaxies, star clusters, Fermi sources, dwarf galaxies, symbiotic stars
- 10 ks ≤ t ≤ 35 ks; |b| < 40º
- ~19,000 targets, ~397 Ms, with 5Ms conflicted (~384 Ms remaining)

Adequate remaining cooling time in any week

Expected to be replaced by targets from the recent CCT call, which will better address current scheduling needs (see morning talks).

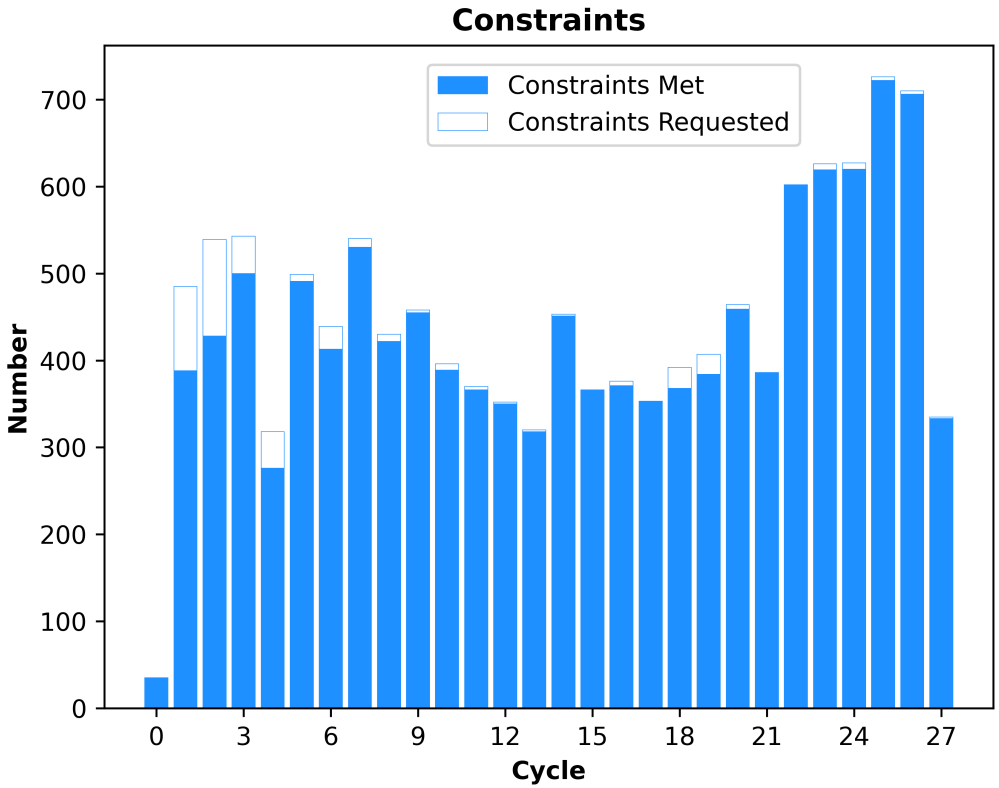
Chandra Cool Targets (CCTs)





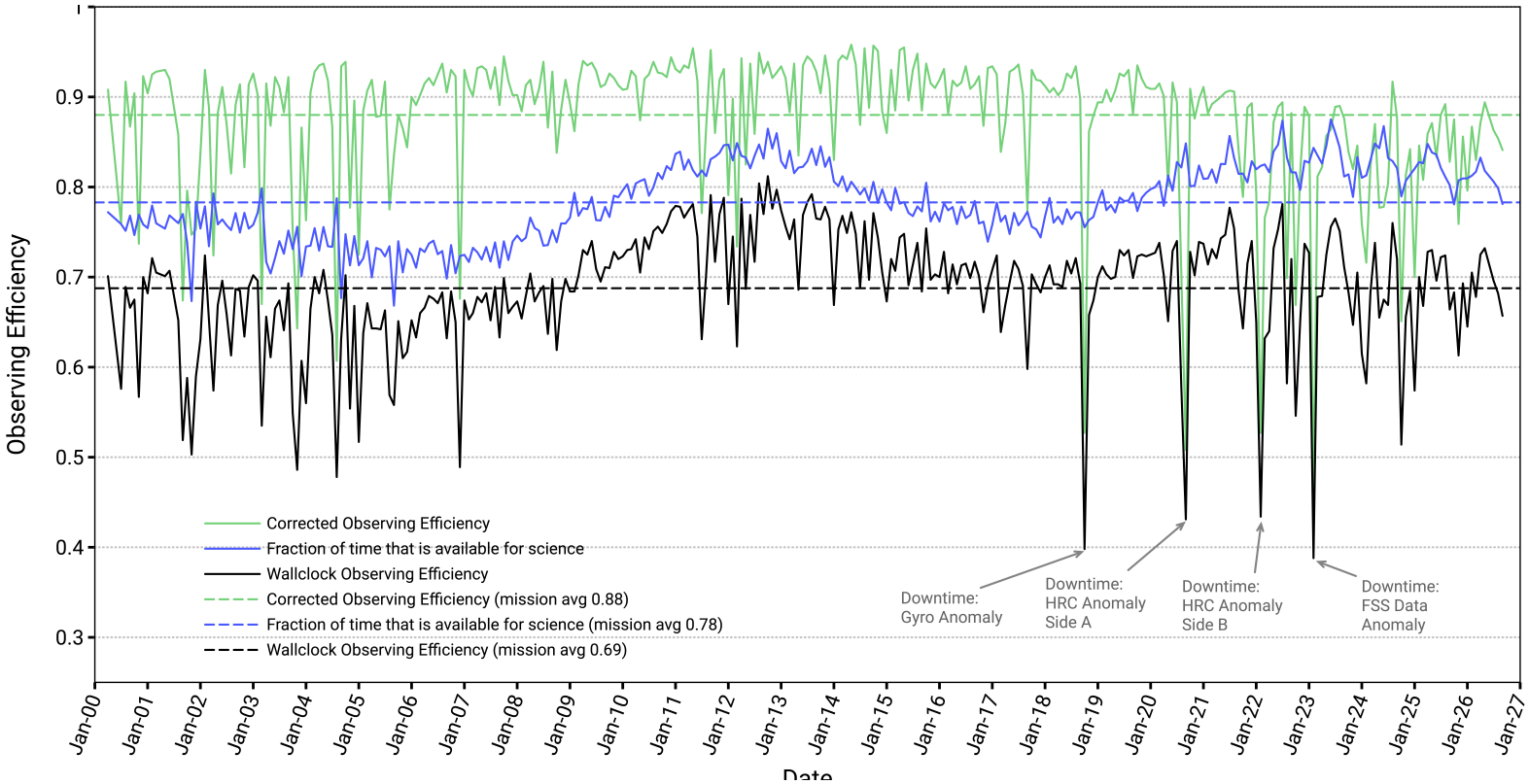
CCT usage “spike” in Cycles 23 - 24, likely driven by recovery from operational events (e.g., HRC power anomaly, IU reset, Fine Sun Sensor issue), and by large programs with particularly difficult star fields observed prior to the ACA flight software patch.

Science Constraints



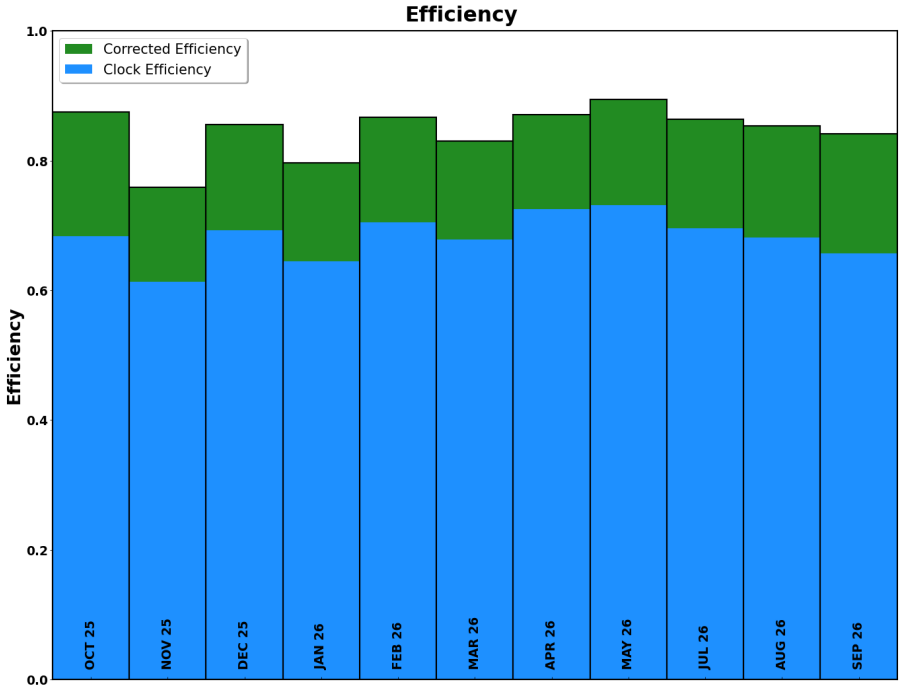
- Difficulty associated with meeting constraints is increasing due to spacecraft thermal limitations (e.g., decrease in maximum dwell times, increasing number of star field constrained targets).
- However, we continue to meet approved observing constraints successfully.
- Most missed constraints are 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.

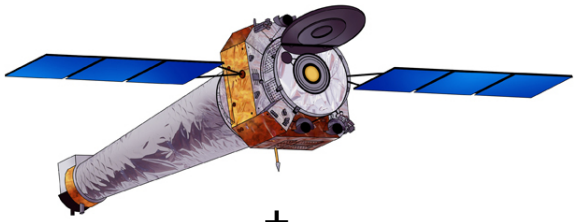
Observation Scheduling



From Sep. 16, 2025 - Sep. 15, 2026:

- Scheduled: 1355 observations (21.7 Ms)
- Executed:
  - 54 TOO observations (1.1 Ms)
  - 27 DDT observations (430 ks)
    - ✧ interrupted 7 operating loads for TOO/DDT support

Coordinated Observations

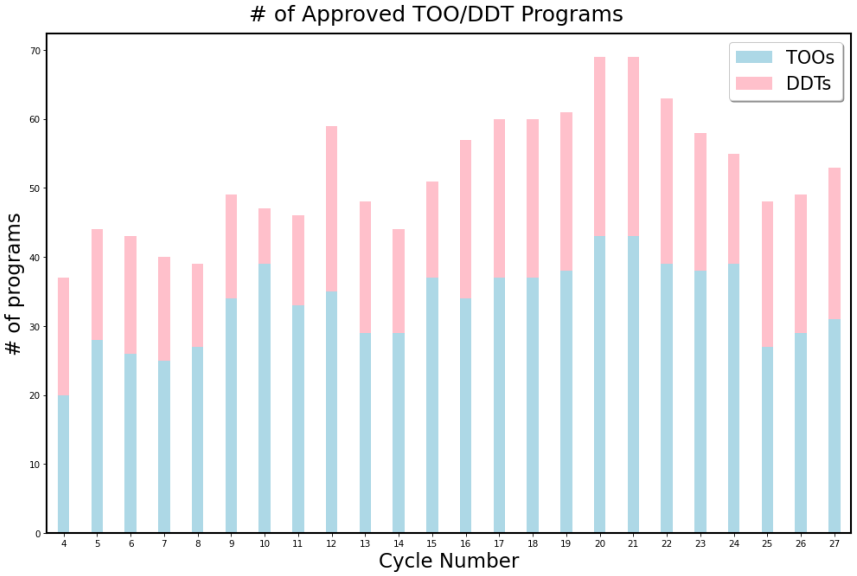


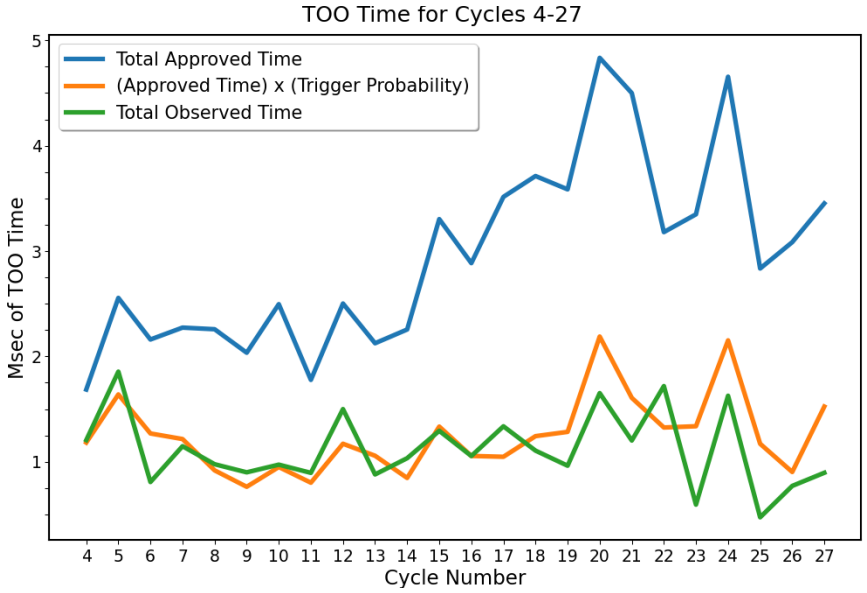
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JWST, HST, NuSTAR, Swift, XMM, IXPE, NICER, VLA, ALMA, EHT

- Chandra Coordinations (Sep. 16 2025 - Sep. 15 2026):
  - 47 observations for 925 ks

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 Work & Issues

- The tank model has very recently becoming the limiting factor in a narrow range of pitch angles. The planning limit is close to the caution limit. Future limit increases will need detailed consideration, and possibly further ground studies.
- Current predictions show that we could “run out” of ObsIDs in as early as three years. The solution to this issue is likely to have broad impact across CXC software and procedures. A working group has recently ben spun up to investigate and propose solutions.
- Redoing study to determine how much high-ecliptic latitude (HEL) time we can tolerate per cycle. Expect results in a few weeks, which could affect the HEL time cap. The previous analysis led to an increase in the cap (from 3 Ms to 4 Ms).
- Study underway to reduce the aspect camera background by sampling during a maneuver, potentially improving the acquisition probability and reduce the impact of poor star fields.
- Reaching out to Roman regarding the possibility of preferentially scheduling weekly “filler targets” in regions that Roman is observing, to support serendipitous TDAMM science.

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

Coming Up in Cycle 24:

- 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

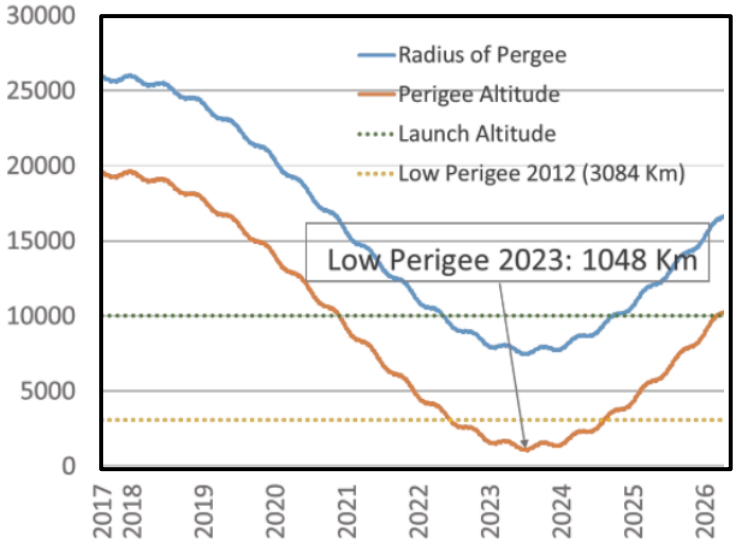
Snapshot of Planning Process

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)					

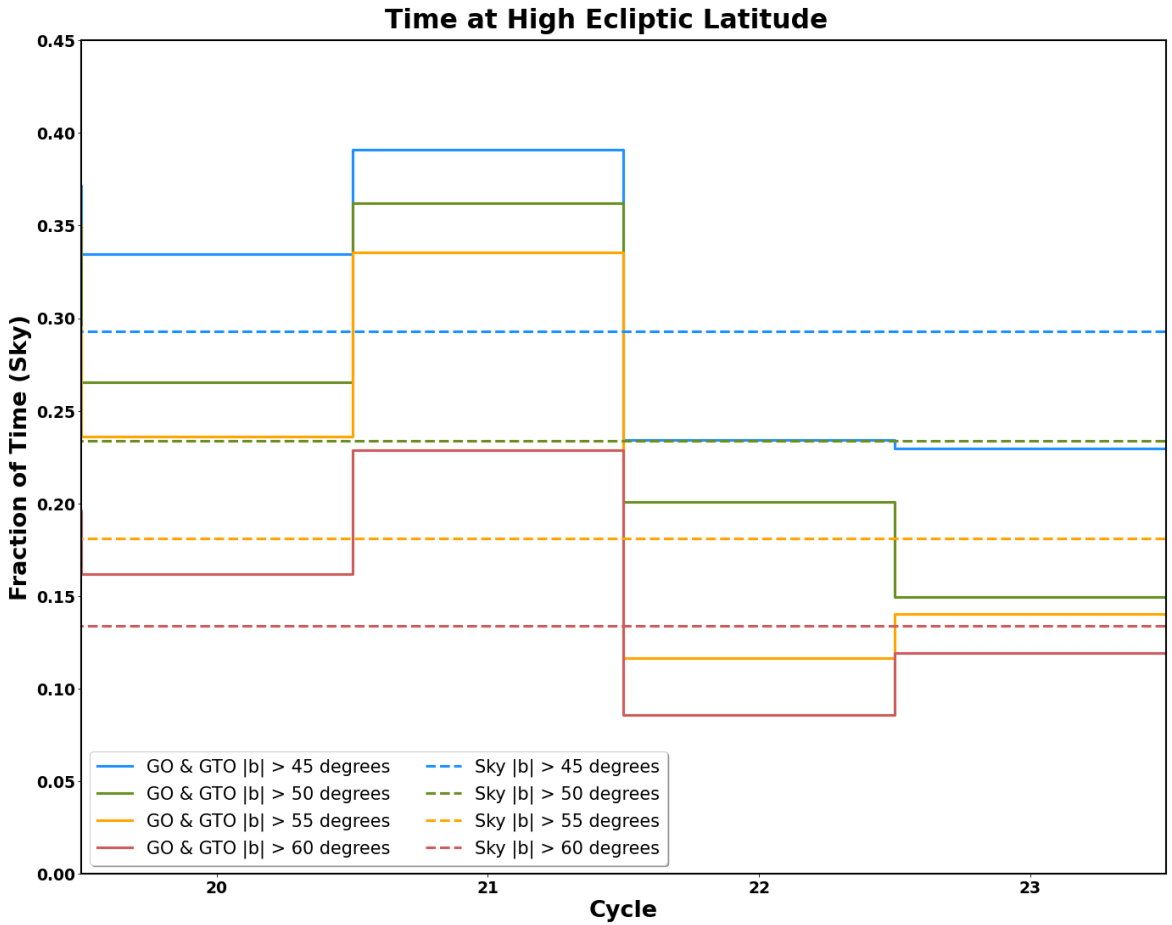
Tool/Process/Limit Updates

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.



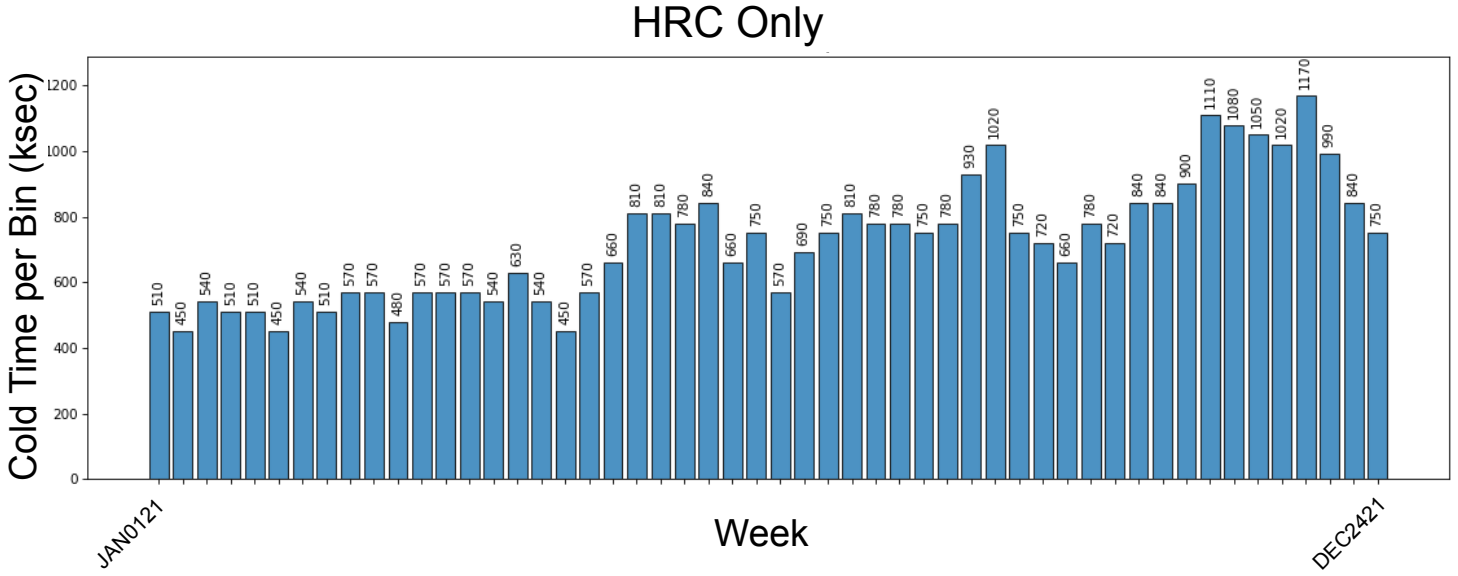
Target Distribution: Cycle 22



- 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>.

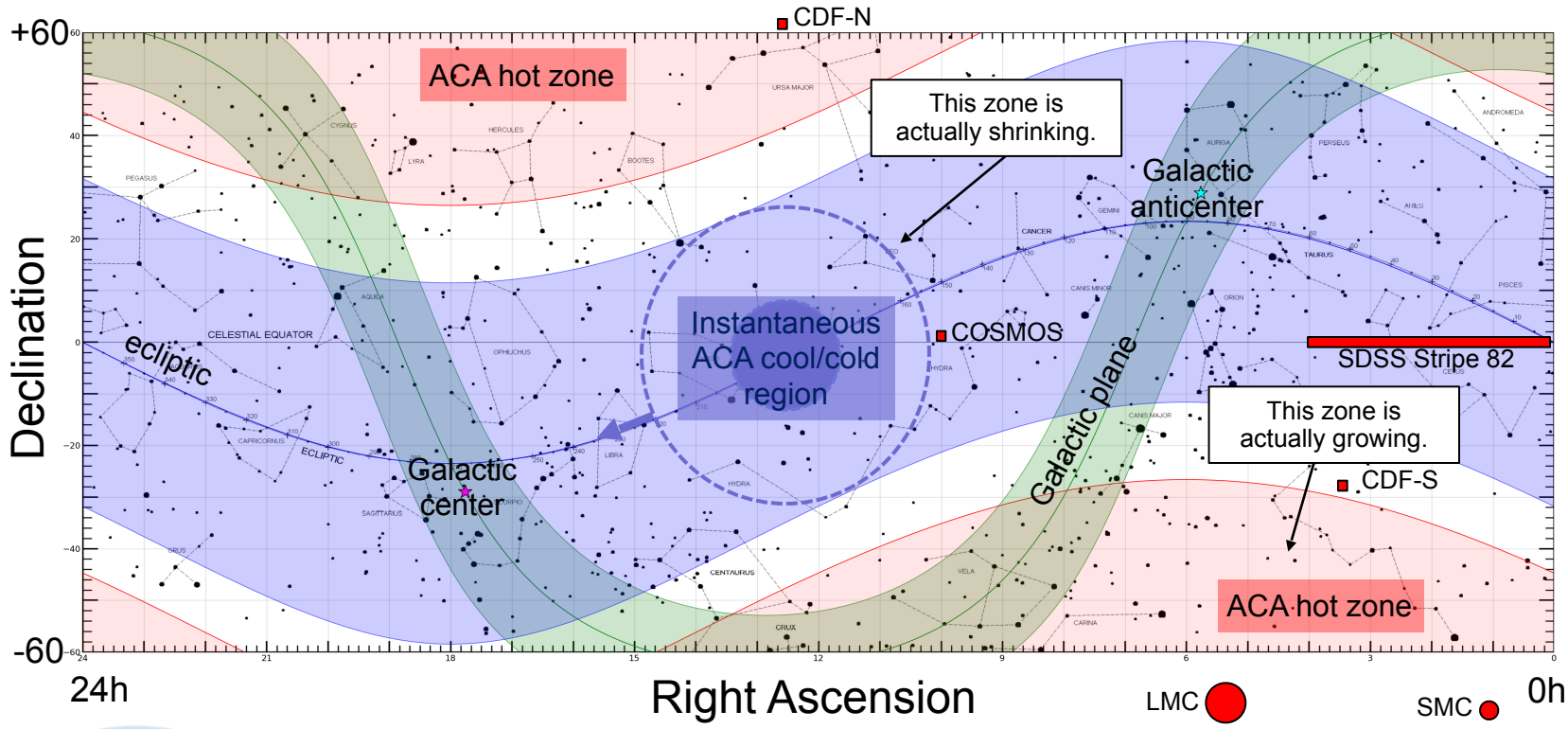
- For several cycles, the CXC has been limiting high ecliptic latitude time in large programs only.
- This has not proven adequate: target times at high β have ended up *above* their proportionate share of sky area.
- Consequences include very long (~6 month) LTS development times and programs that extend 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.

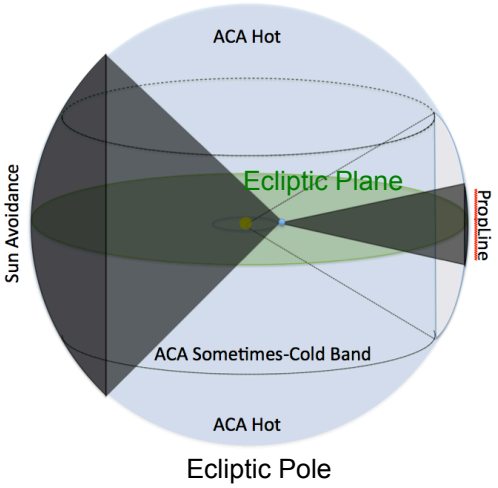
Chandra Cool Targets (CCTs)



- 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



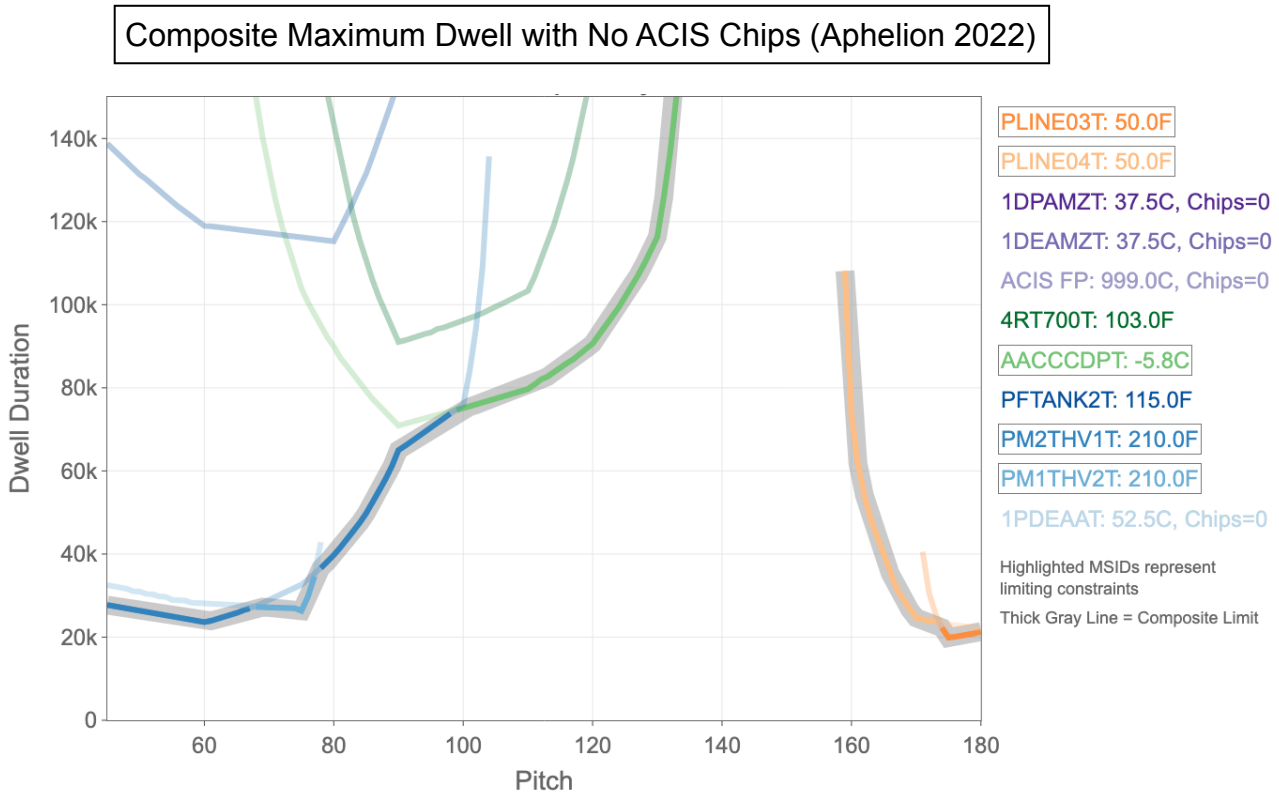


- Sometimes-cool/cold ACA (-Z) region covers large sky area.

  - 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.