Mission Planning Updates

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On behalf of SOTMP:
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Overall Context for Mission Planning

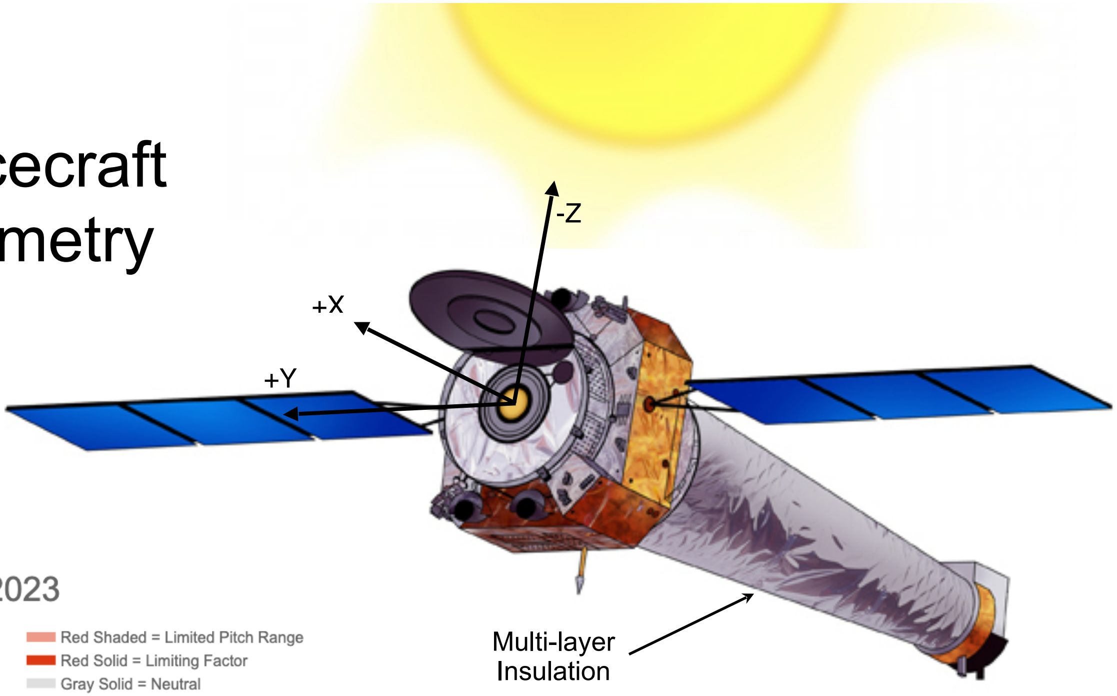
Goal:
Maximizing the science return of the mission in the presence of constraints:

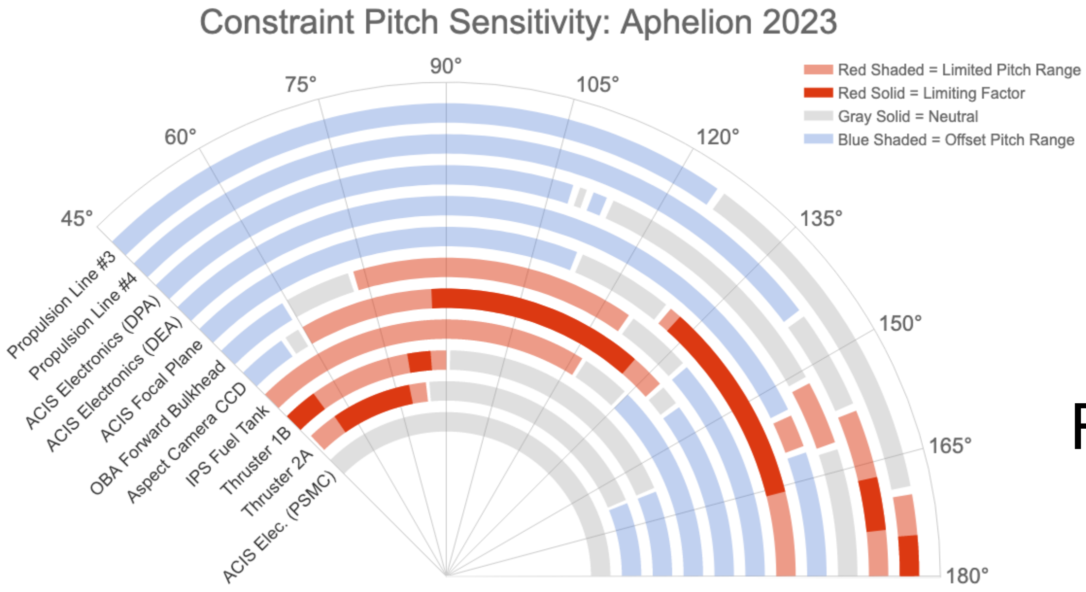
Observation constraints, e.g.,
- coordination
- time windows
- continuity of observations
- monitoring series and observation grouping
- roll constraints
- phase constraints

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

Chandra Thermal Restrictions

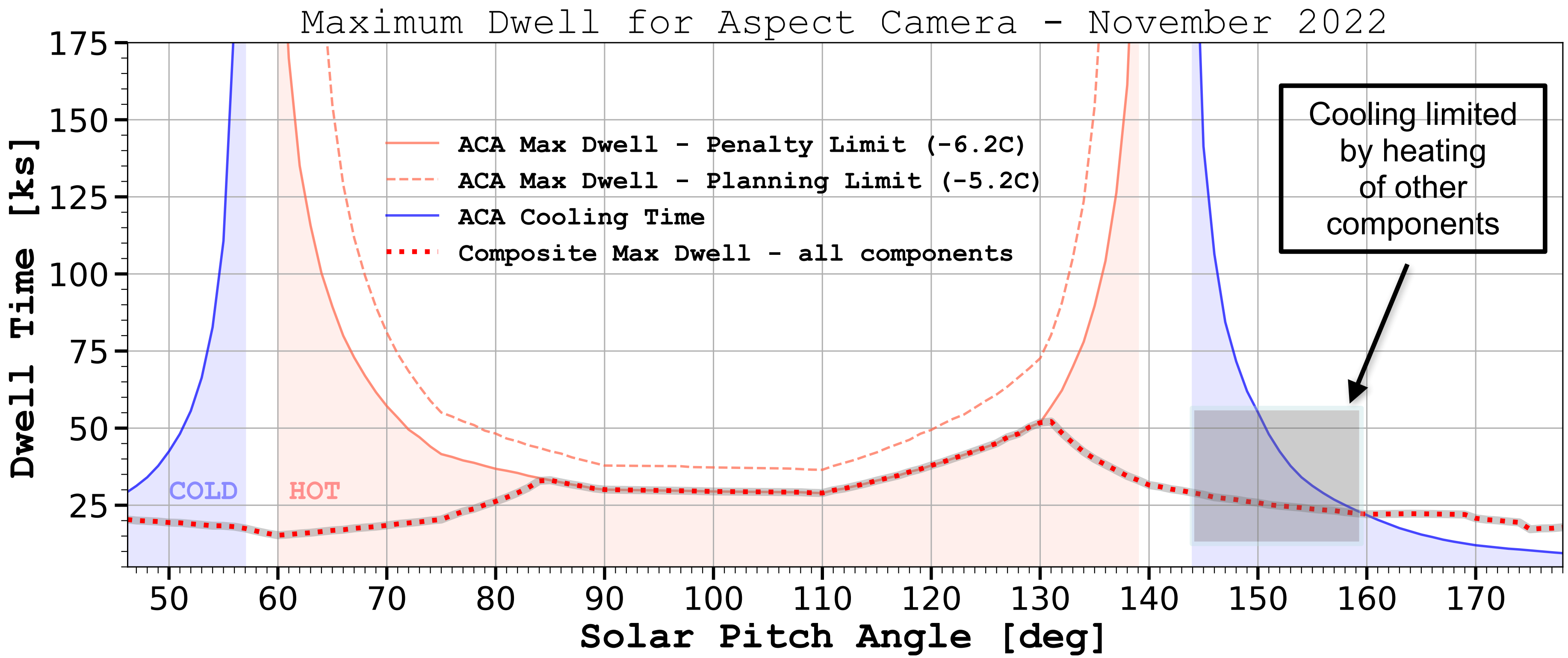
Spacecraft Geometry





Thermal Restrictions

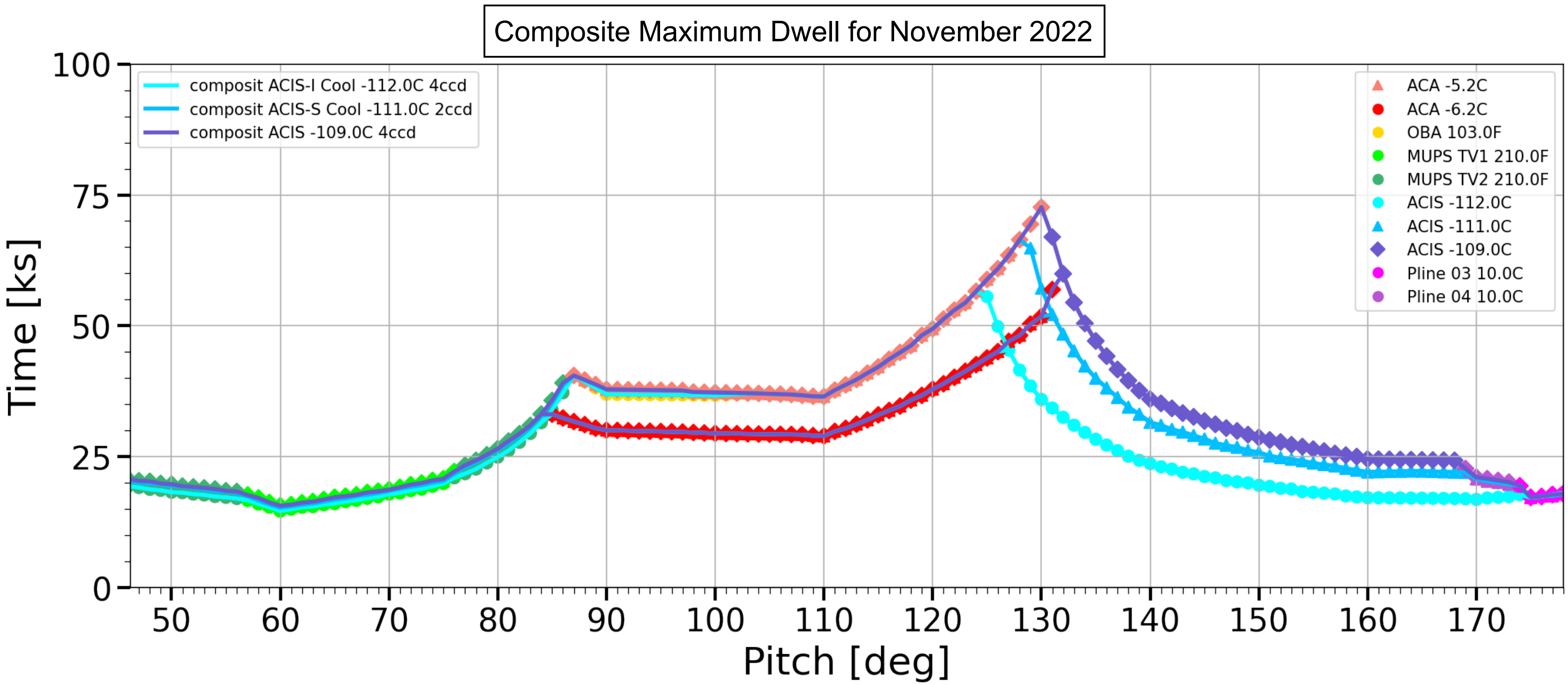
Thermal Balance: A Summary



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

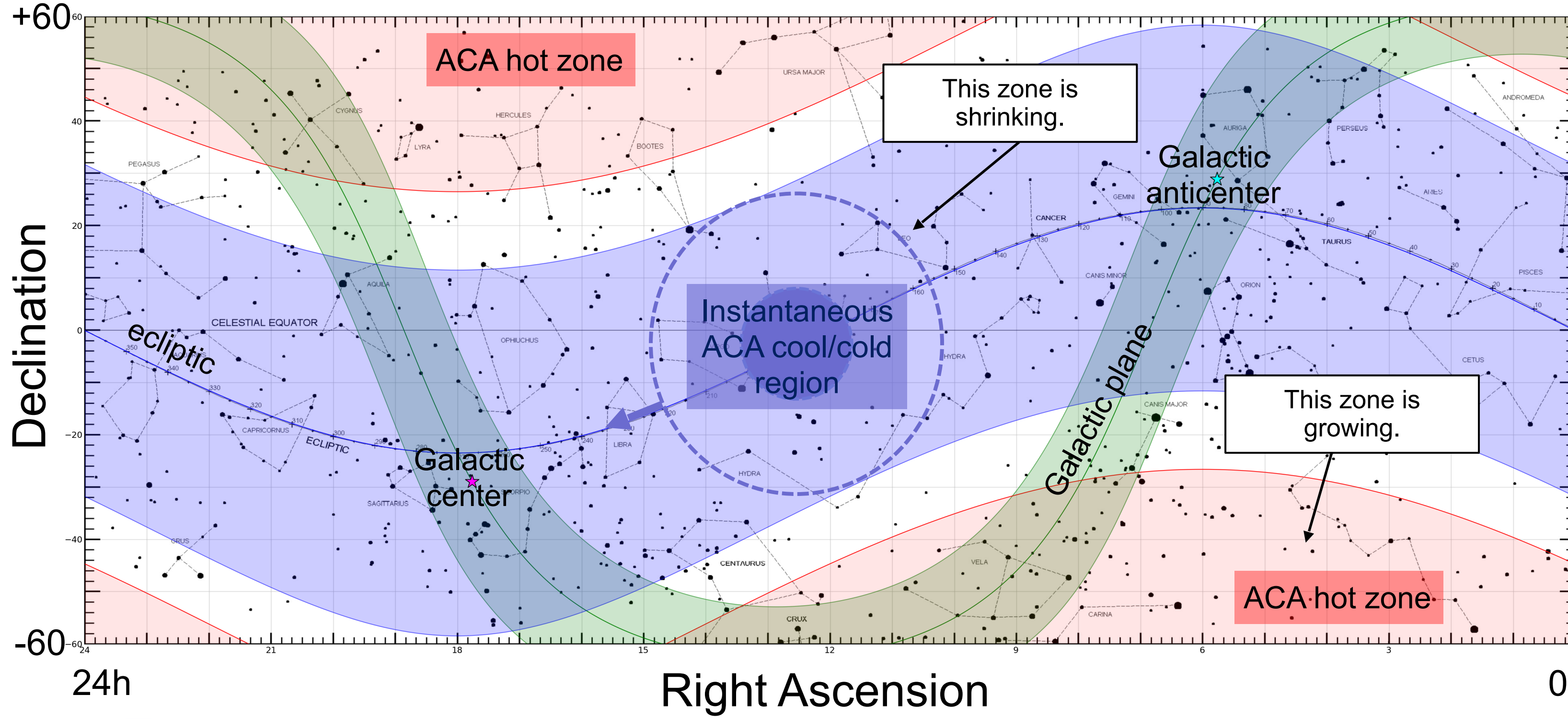
Blue: minimum cooling time required to return to state from which another max dwell possible

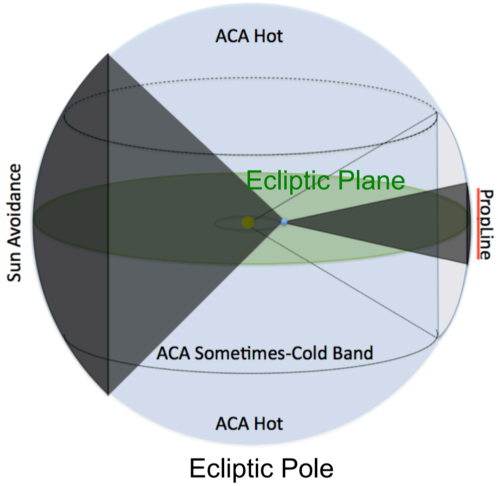
Thermal Balance: A Summary



- "Hot ACA" region (~ 90<pitch<130) now more favorable compared with other regions
- We have been working hard to stay ahead of rising temperatures with component planning 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 85 deg (and rising) pitch

Constraints: Sky View





- The sometimes-cool/cold ACA (-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

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

#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

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. The initial schedule for "Cycle 24" was completed in October 2022, much earlier than just a few years ago.

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
- This problem is expected to get worse with time, and some star fields may already be unobservable

Tool/Process/Limit Updates

Star Field Checker Tool

- Impending release of a new star field checked webtool, that proposers will be able to use for AO 25
- For any pointing parameters, the tool returns the roll angle (and corresponding date) ranges where the star field is acceptable
- If no acceptable roll angles are found, the user is encouraged to contact the HelpDesk for a detailed "by hand" check
- Ultimately, we expect that this tool will be incorporated into CPS, for ease-of-use during proposal submission

Tool/Process/Limit Updates

Increase in the Default Dither Amplitude

- It was realized that increasing the default dither amplitude from 8"x8" to 16"x16" would improve star acquisition and guide probabilities
- Default dither parameters and aimpoints (to avoid chip edges) were updated accordingly
- Implemented for observations proposed in cycle 24 and beyond
- This means fewer star constrained fields

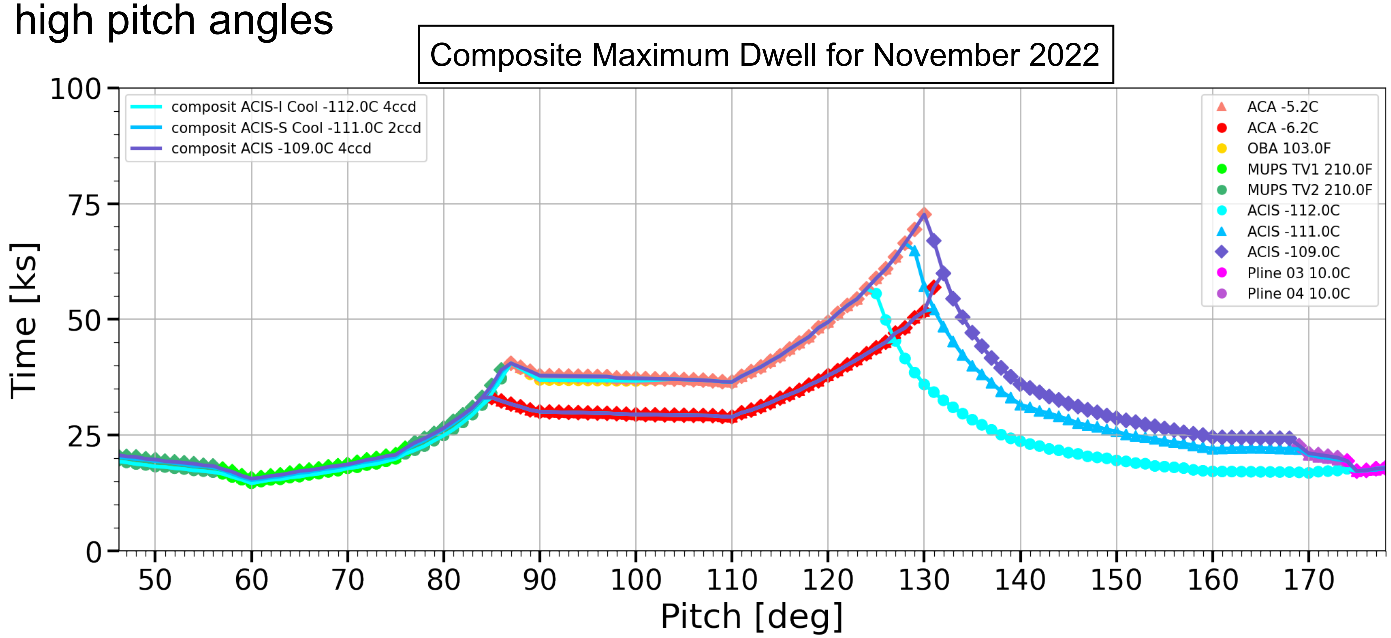
Tool/Process/Limit Updates

High Ecliptic Latitude (HEL) Time Limit

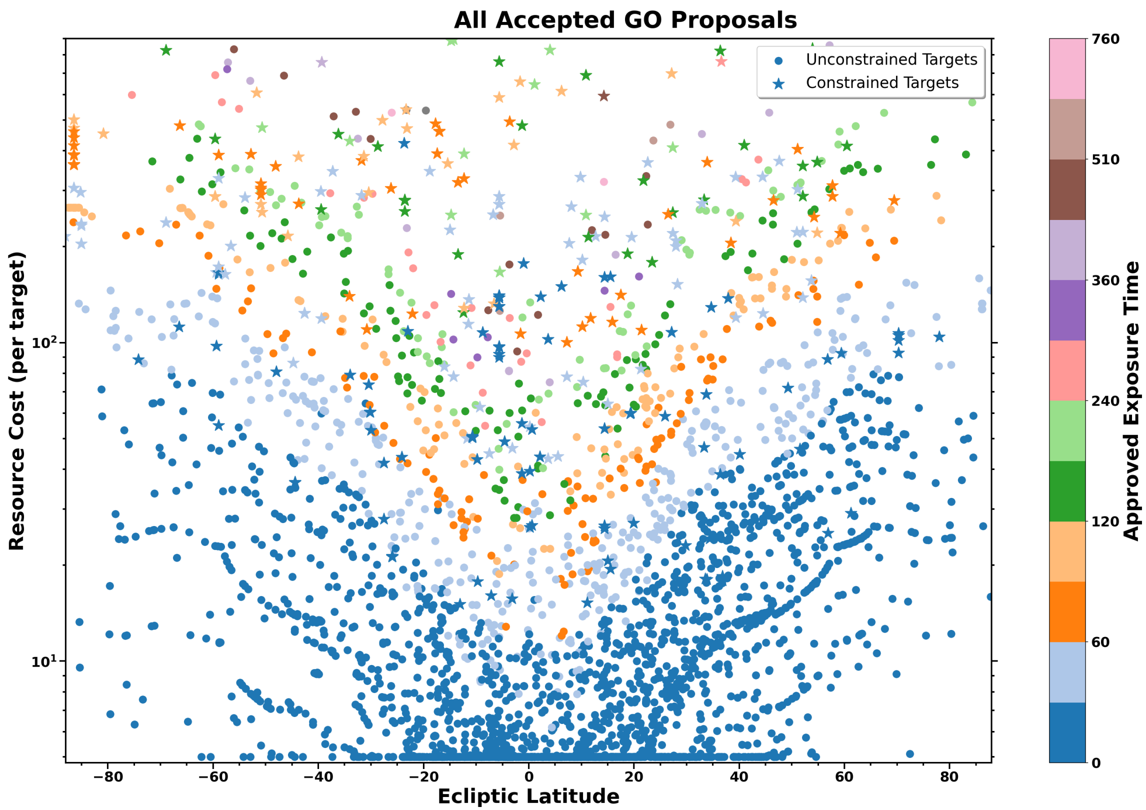
- In Cycle 24, observing time assigned by peer review at high ecliptic latitudes ($|\beta|$ >55°) was increased to from 2.5 Msec to 3 Msec, to reflect the decreased dominance of the ACA temperature limit
- Looking into further increasing the high ecliptic latitude total (HEL) time limit at peer review, to reflect the evolution of solar pitch angle constraints

Default ACIS Focal Plane Temperature Limit Increase

- The new default limit for all ACIS observations is -109 C
- Provides signifiant relief for weekly scheduling, since it allows longer dwell times at high pitch angles



Resource Cost



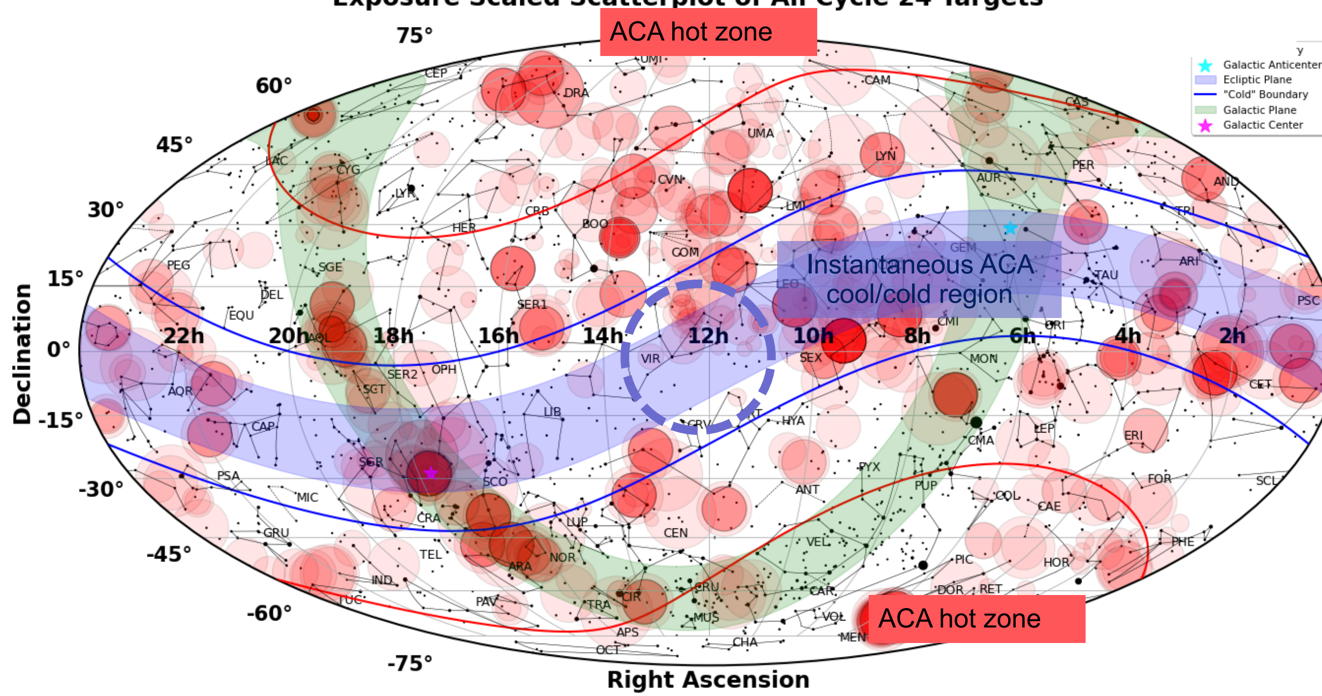
Resource Cost (RC) values for observing programs from *Chandra* Cycles 14-24.

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

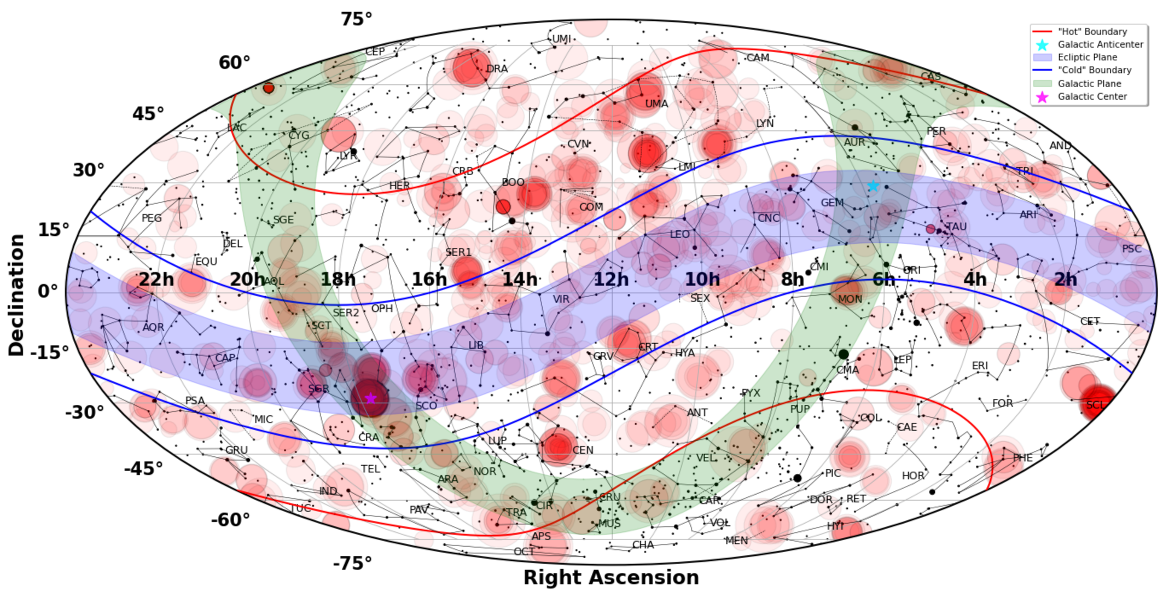
- Introduced in cycle 22.
- Replaces "constraint categories" (easy/average/difficult) used in previous cycles.
- Calculated for all non-TOO targets.
- On current (arbitrary) scale, peer review assigns total cost ~32,000.
- For Cycle 25: minor fixes, and calculated new pitch weighting to not as strongly disfavor HEL targets
- Potential resource-cost-like scoring for TOOs (currently only the number of triggers by category are tracked, so a fast 100 ks TOO is equivalent to a fast 1 ks TOO)

Target Distributions

Exposure Scaled Scatterplot of All Cycle 24 Targets

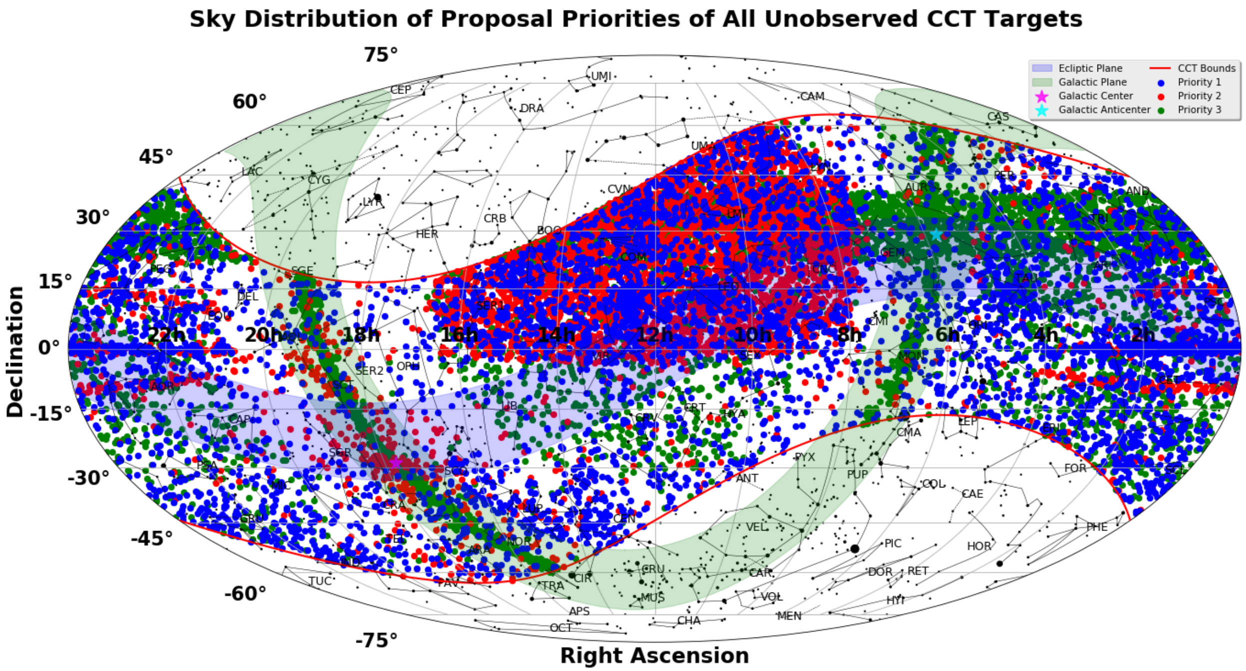


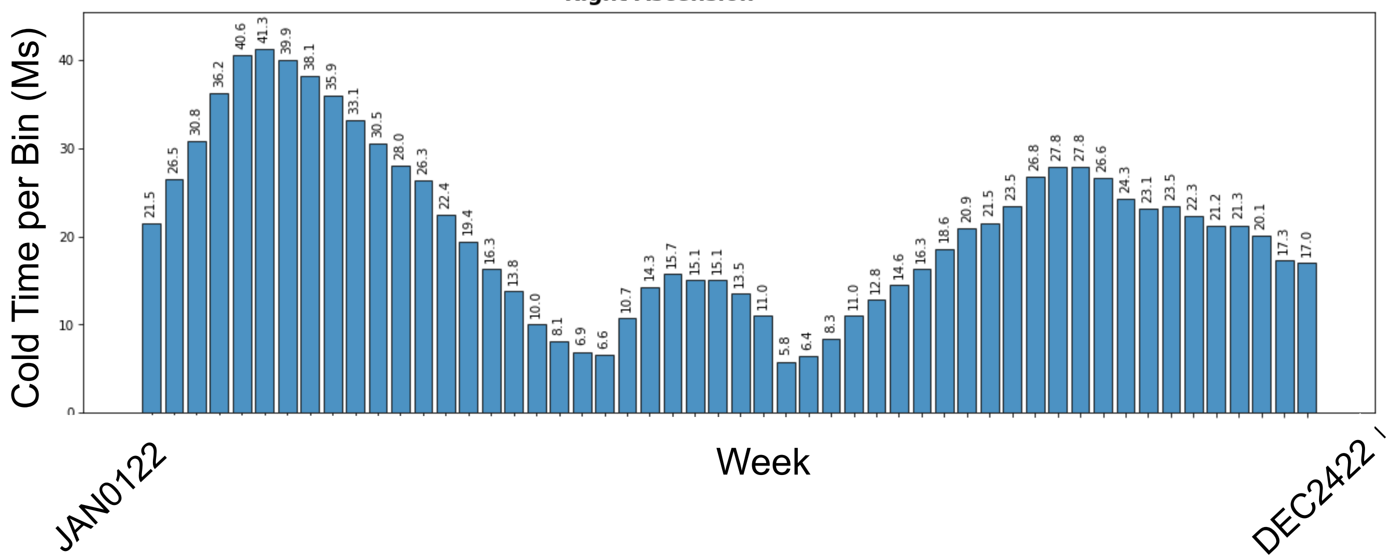
Exposure Scaled Scatterplot of All Targets Observed NOV0121 to NOV0122



S. Randall (Chandra Mission Planning)

Chandra Cool Targets (CCTs)





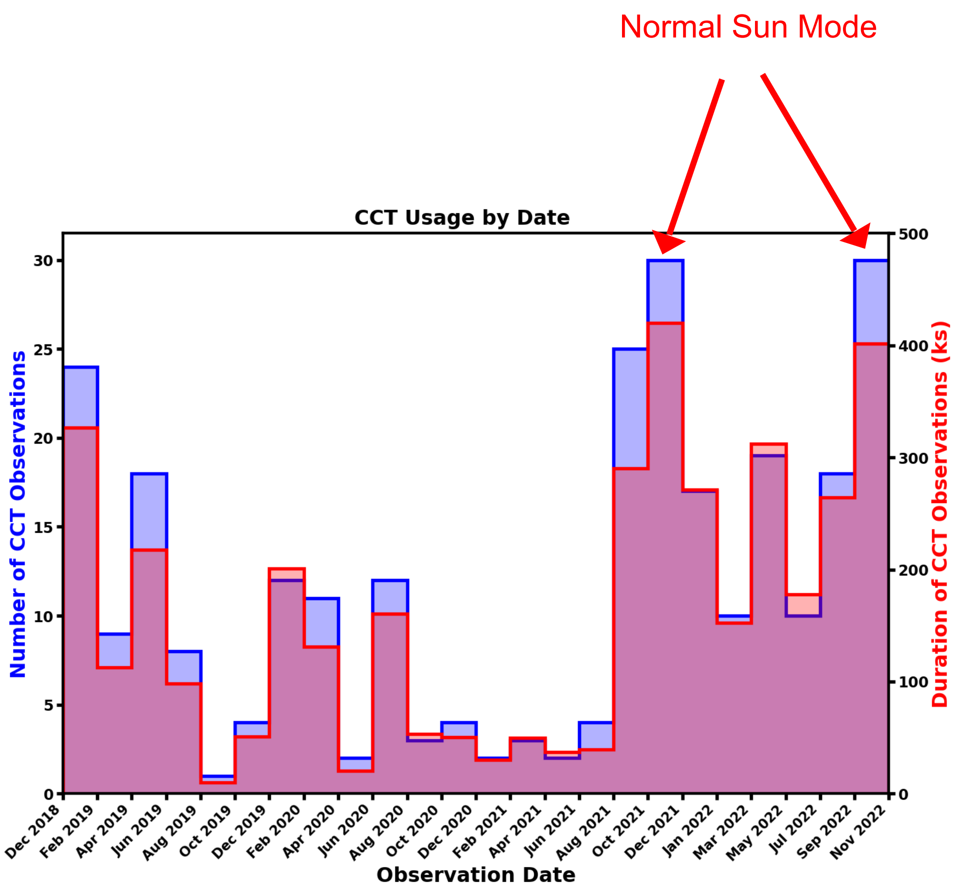
- 22 programs
- Include:

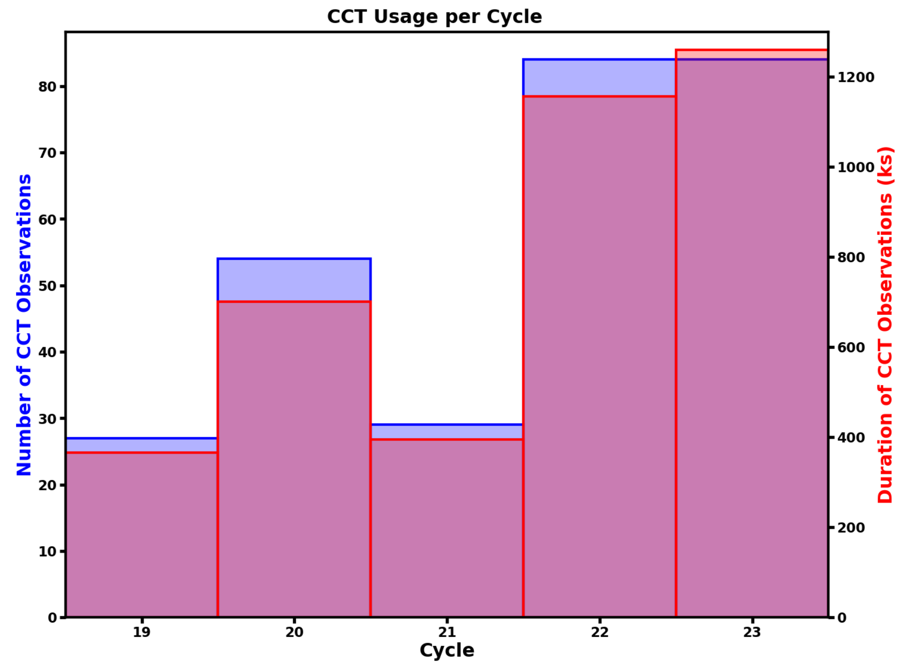
galaxy clusters, ULXs quasars, AGN, HMXBs CVs, SFRs, cool stars, survey counterparts, radio galaxies, star clusters, Fermi sources, dwarf galaxies, symbiotic stars

10 ks ≤ t ≤ 35 ks; |b| < 40º

- Includes:
  - ~19,000 targets
  - ~400 Ms in time
- Adequate cooling time in any week

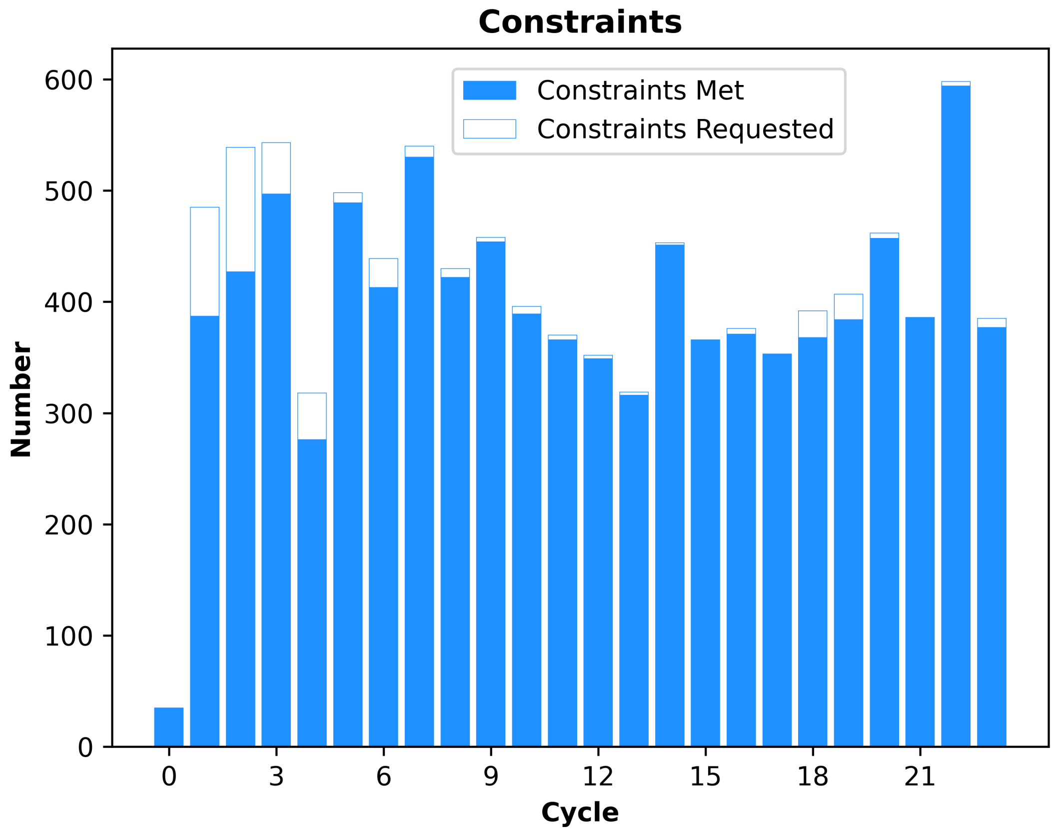
Chandra Cool Targets (CCTs)





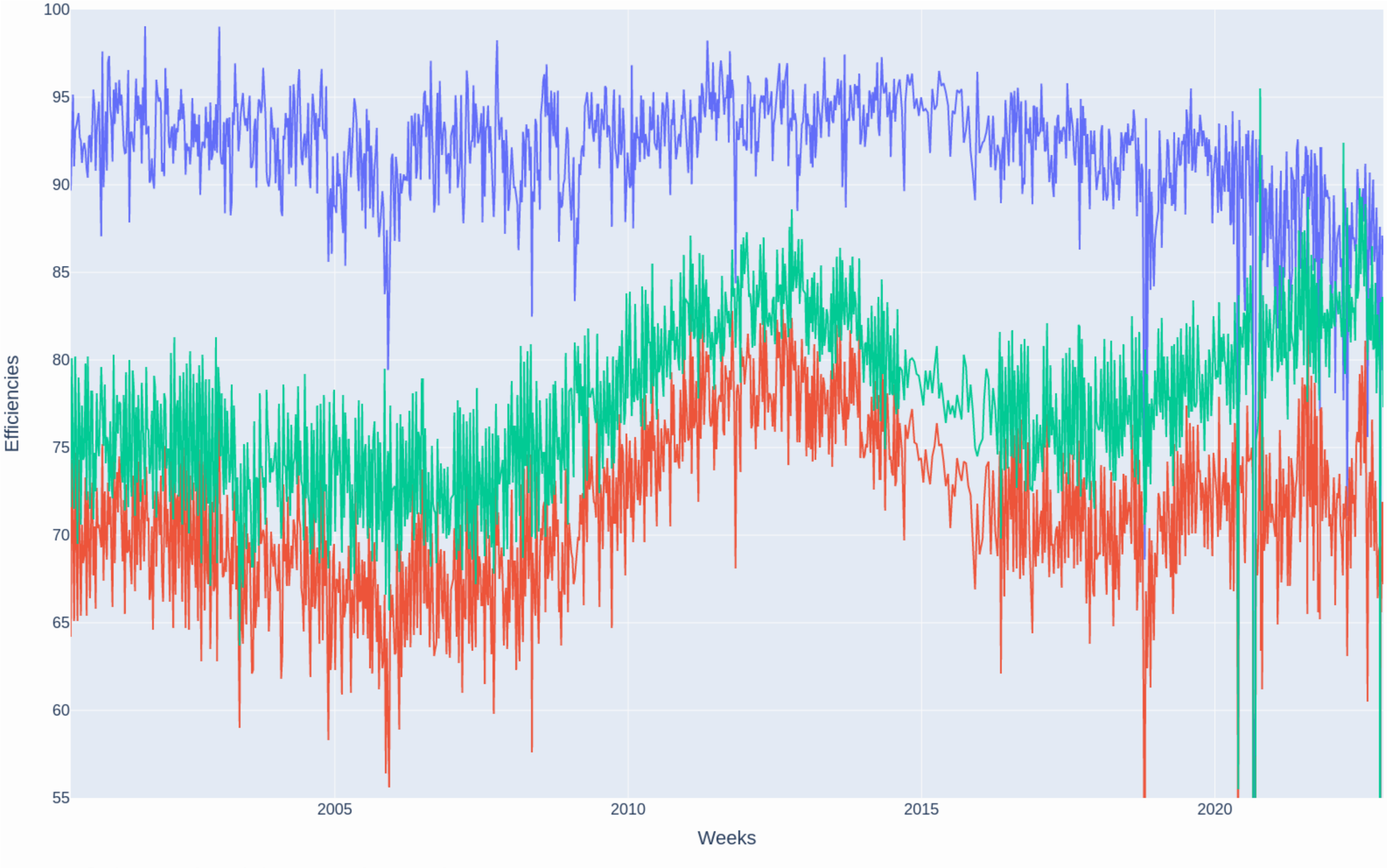
CCT usage is showing some signs of increasing over the past year, although this is probably partially driven by recovery from operational events (e.g., IU reset, momentum monitor trip)

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

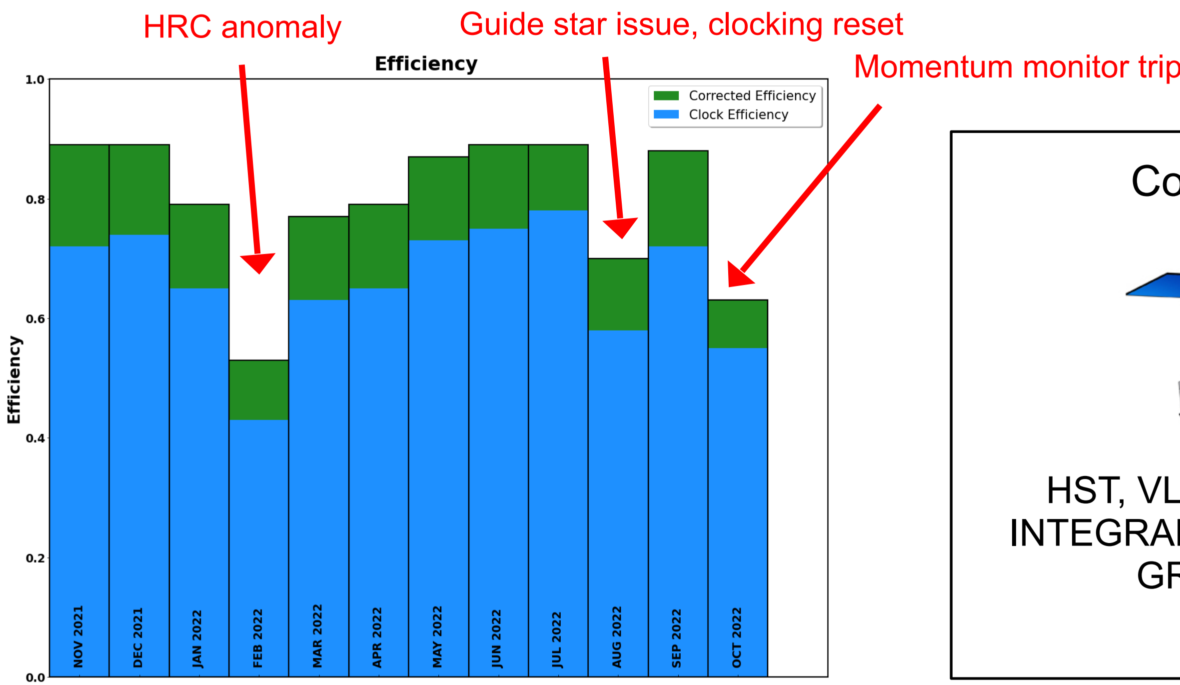


Science time/above radzone time.

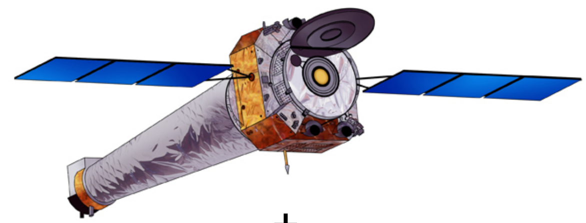
Above radzone time/wallclock time.

Science time/wallclock time.

Observation Scheduling



Coordinated Observations



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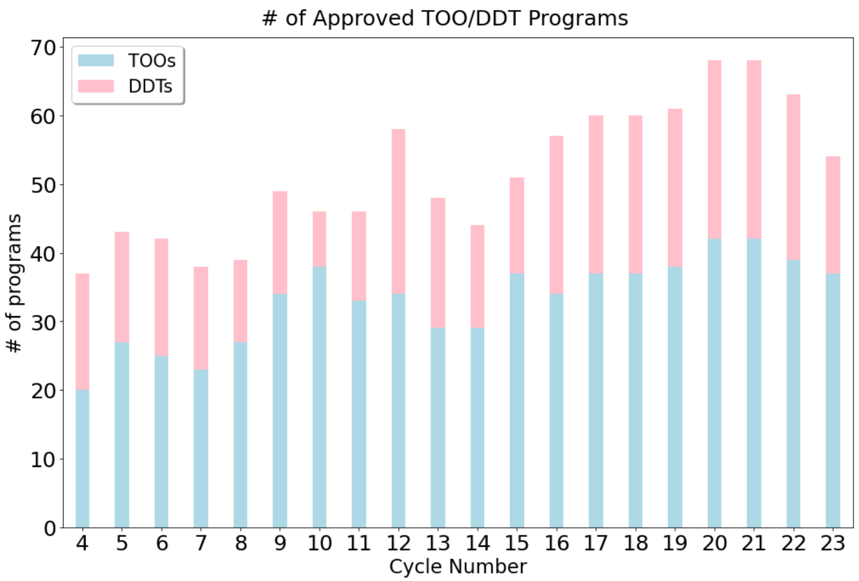
HST, VLA, NuSTAR, Swift, XMM, Astrosat, INTEGRAL, NICER, EHT, ATCA, Gemini, VLTI/GRAVITY, Effelsberg, eROSITA

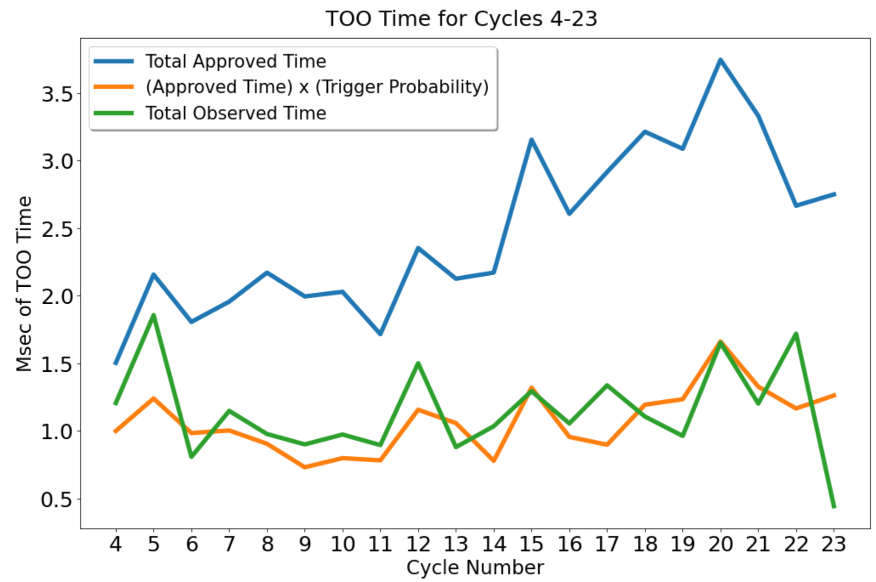
From Nov. 1, 2021 - Nov. 1, 2022:

- Scheduled: 1466 observations (20.9 Ms)
- Executed:
  - 39 TOO observations (722 ks)
  - 54 DDT observations (536 ks)
    - ✧ interrupted 1 operating loads for TOO/DDT support

- Chandra Coordinations (Nov. 1 2021 - Nov. 1 2022):
  - 64 observations for 1.3 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

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 greatly complicates constructing the long term schedule and detailed weekly planning, e.g. due to component temperature limits and an increase 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, and TOO/DDT response, and science constraint compliance that are on par with mission history

Backup Slides

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

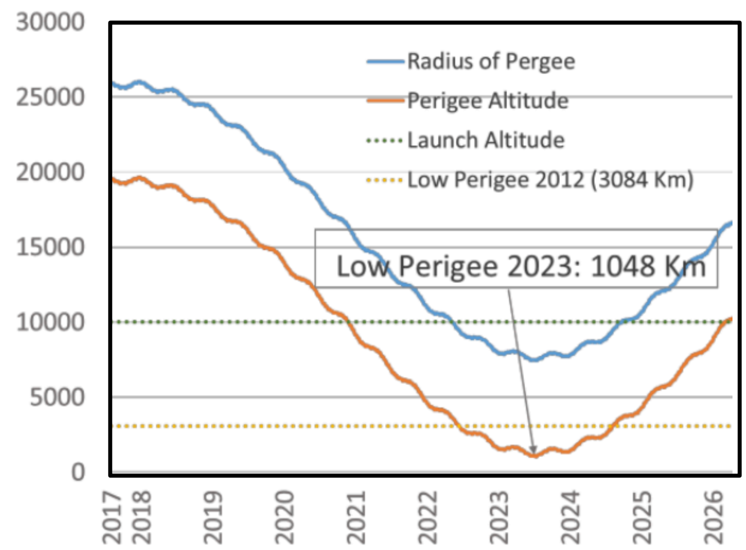
Snapshot of Planning Process

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)					

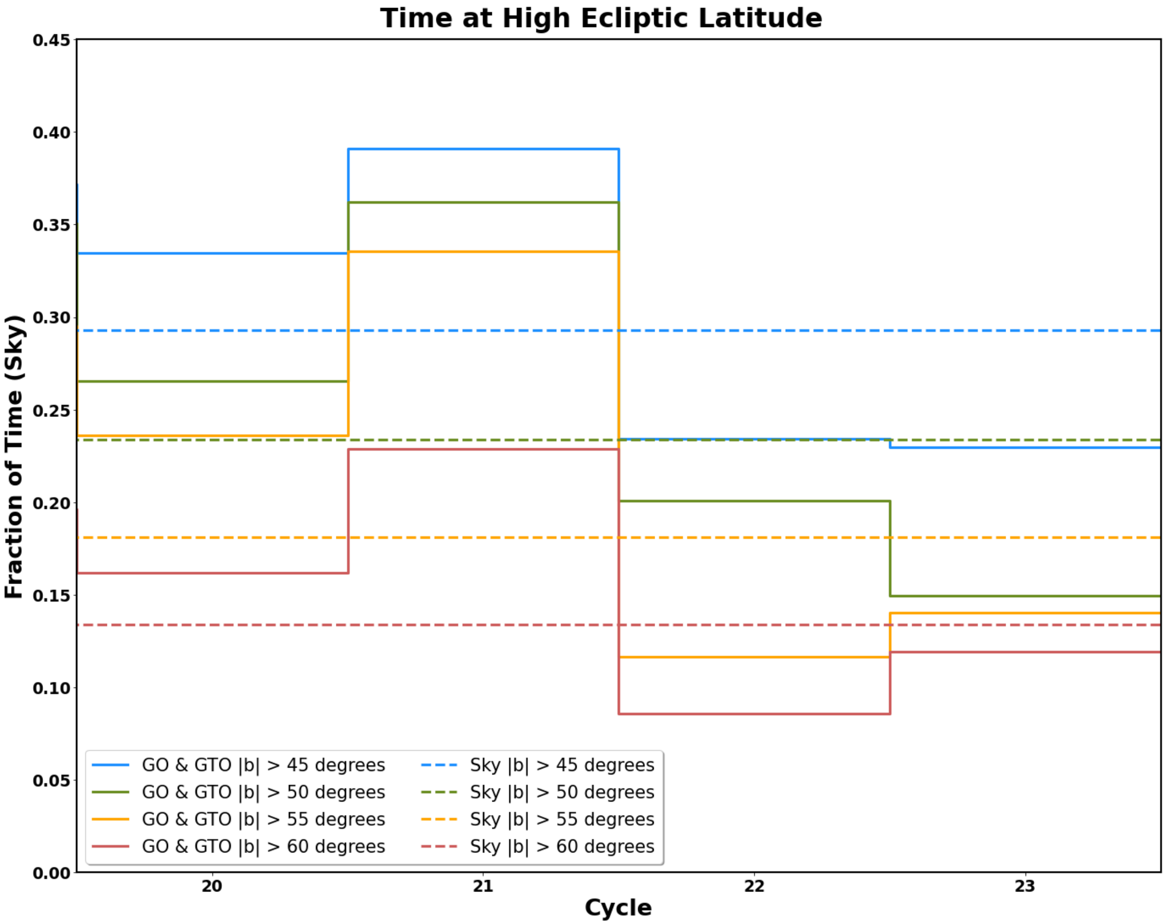
Tool/Process/Limit Updates

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.



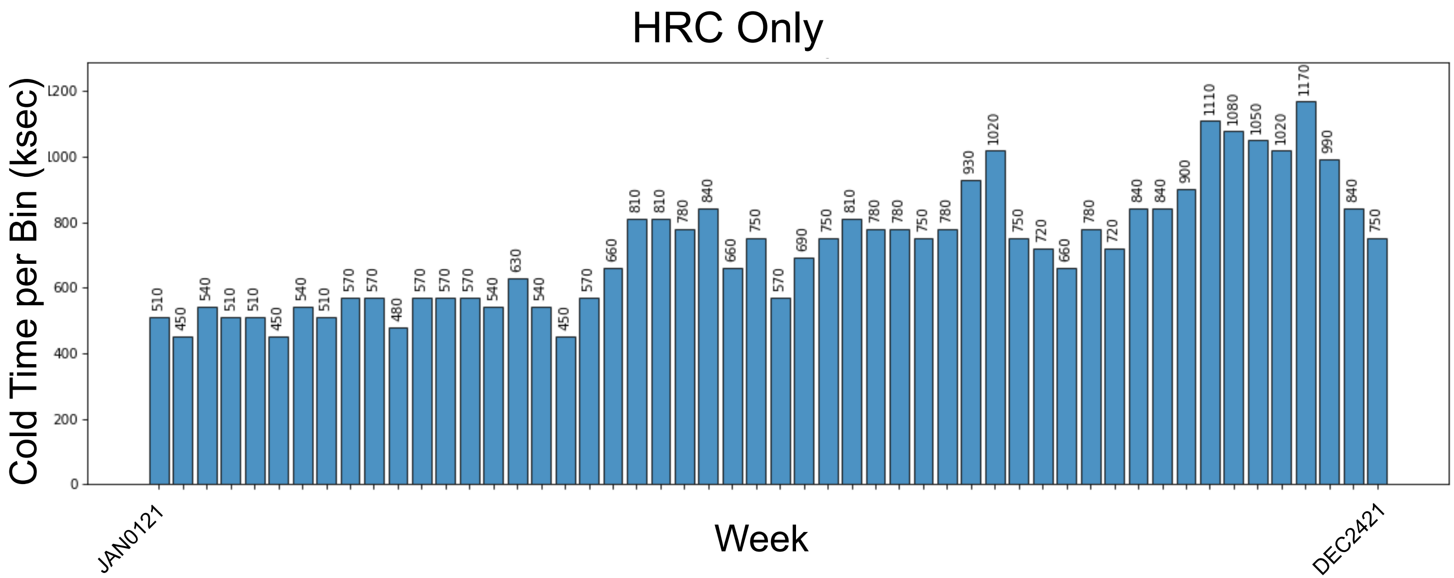
Target Distribution: Cycle 22



- 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)

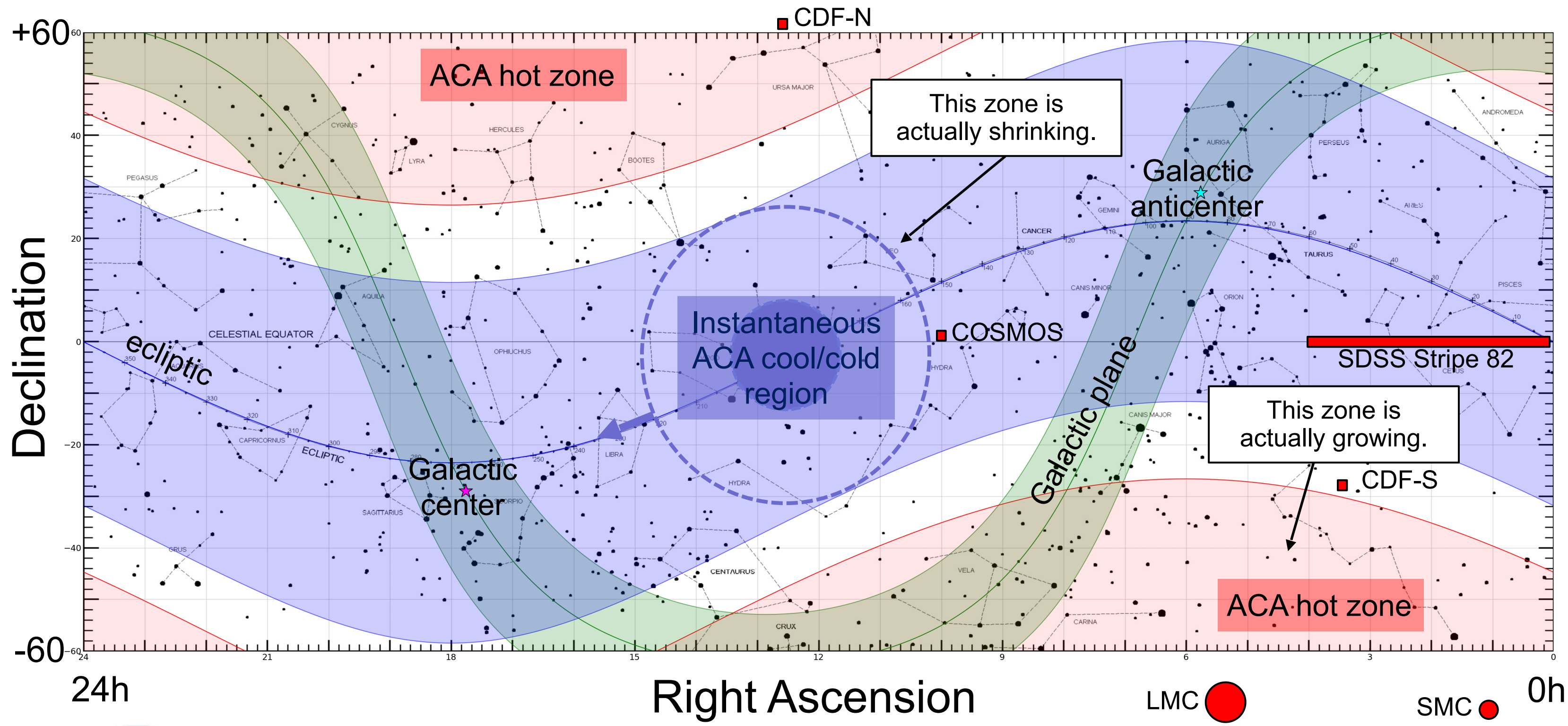


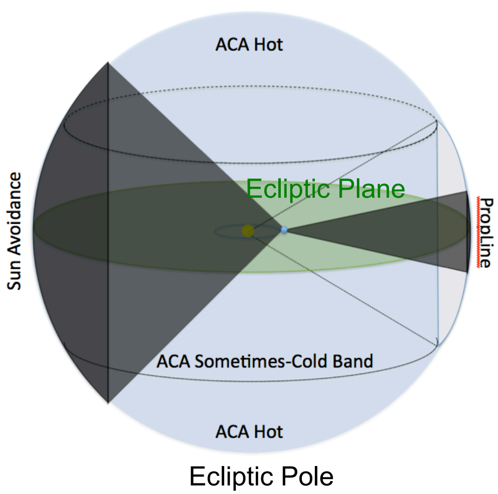
- Recall that cold HRC observations are particularly useful for thermal management, since ACIS is the main limiting factor at high pitch angles.

- 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





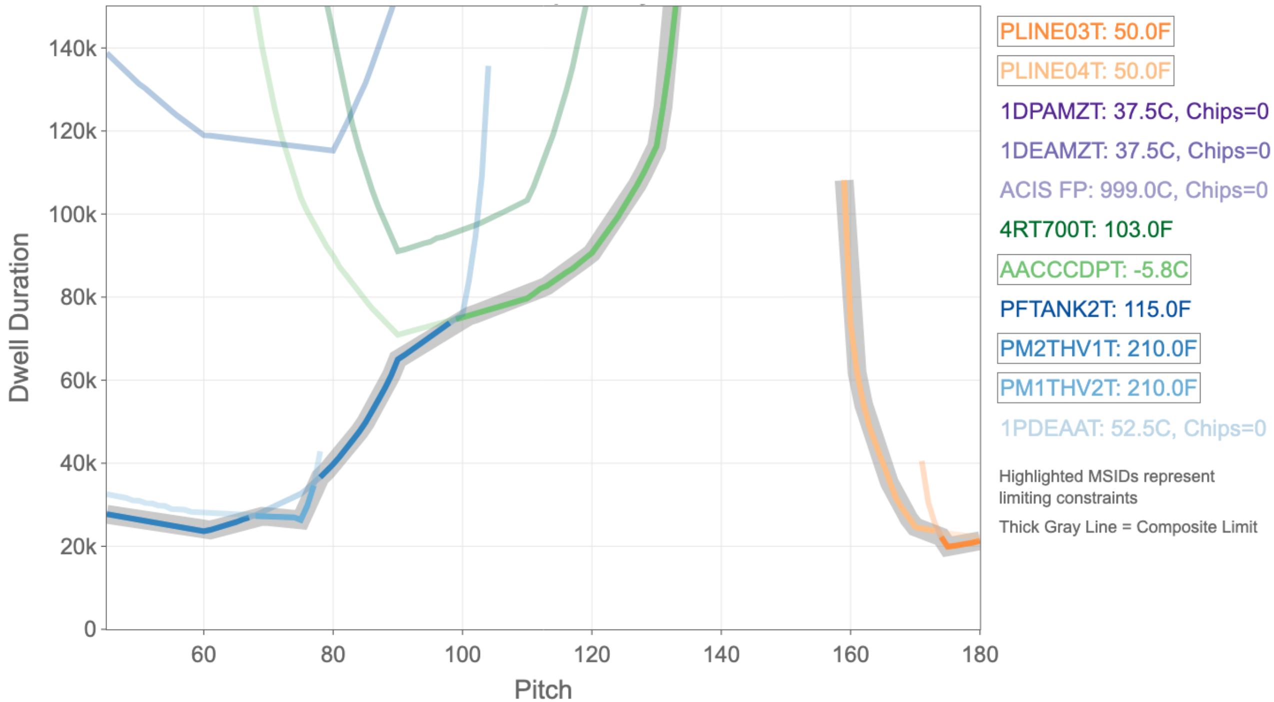
- Sometimes-cool/cold ACA (-Z) region covers large sky area.

  - 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

Composite Maximum Dwell with No ACIS Chips (Aphelion 2022)



- 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.