# Mission Planning Updates

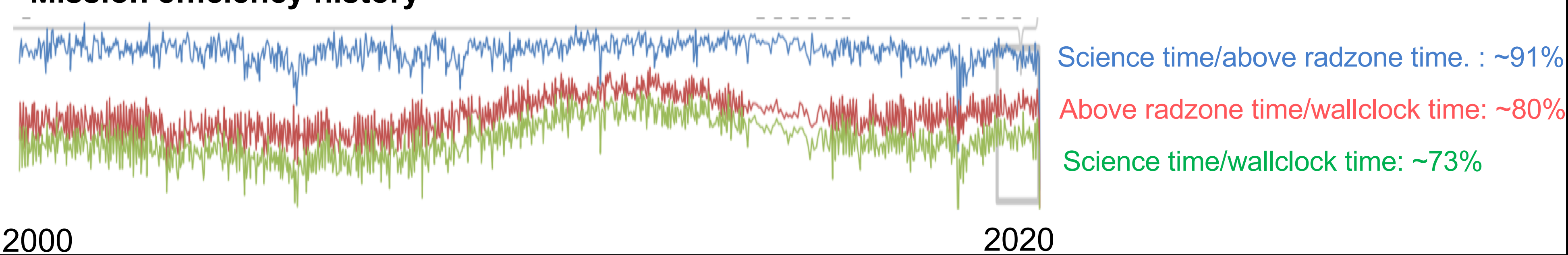
# Overall Context for Mission Planning

*Goal:*

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

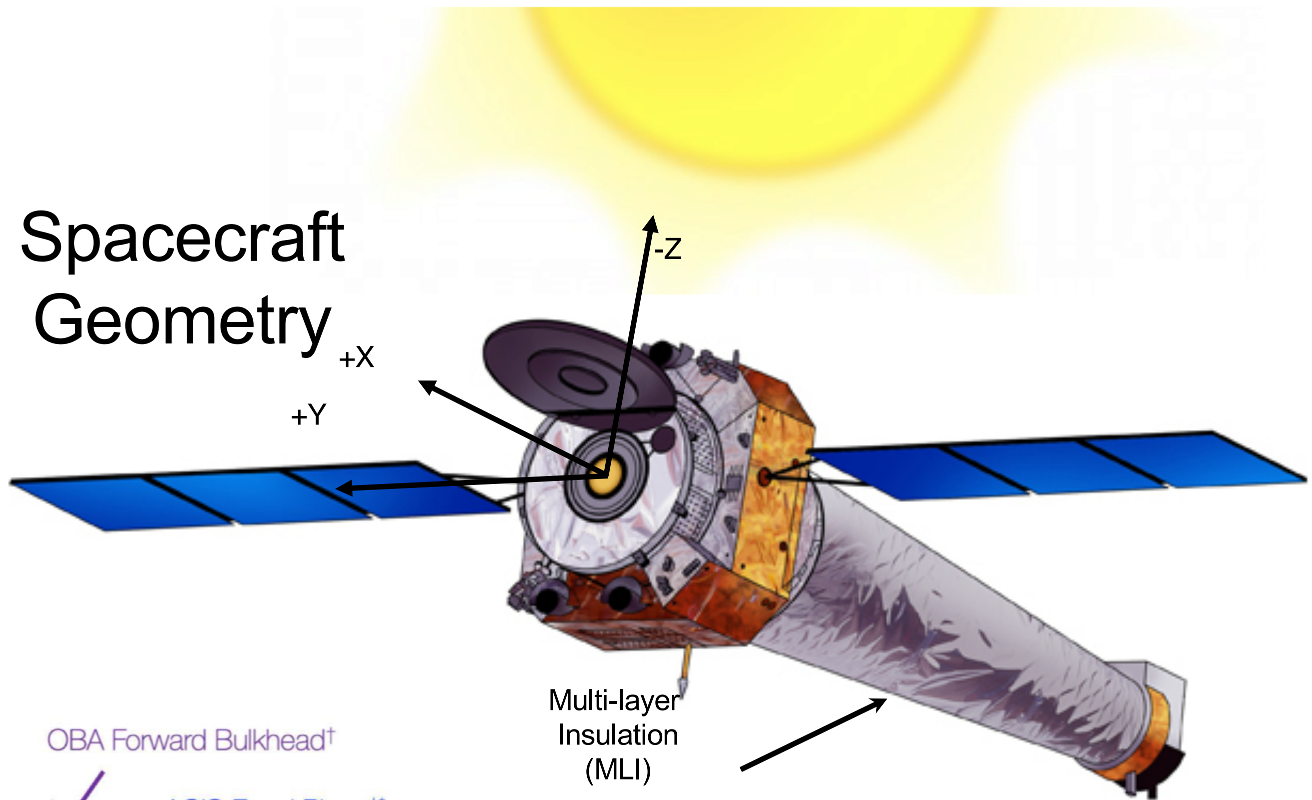
- Observation constraints, e.g.,
  - coordination
  - time windows
  - continuity of observations
  - monitoring series and observation grouping
  - roll constraints
- Engineering constraints, e.g.,
  - *thermal constraints*
  - momentum management
  - Sun, Moon, Earth, bright X-ray source avoidance

**Mission efficiency history**

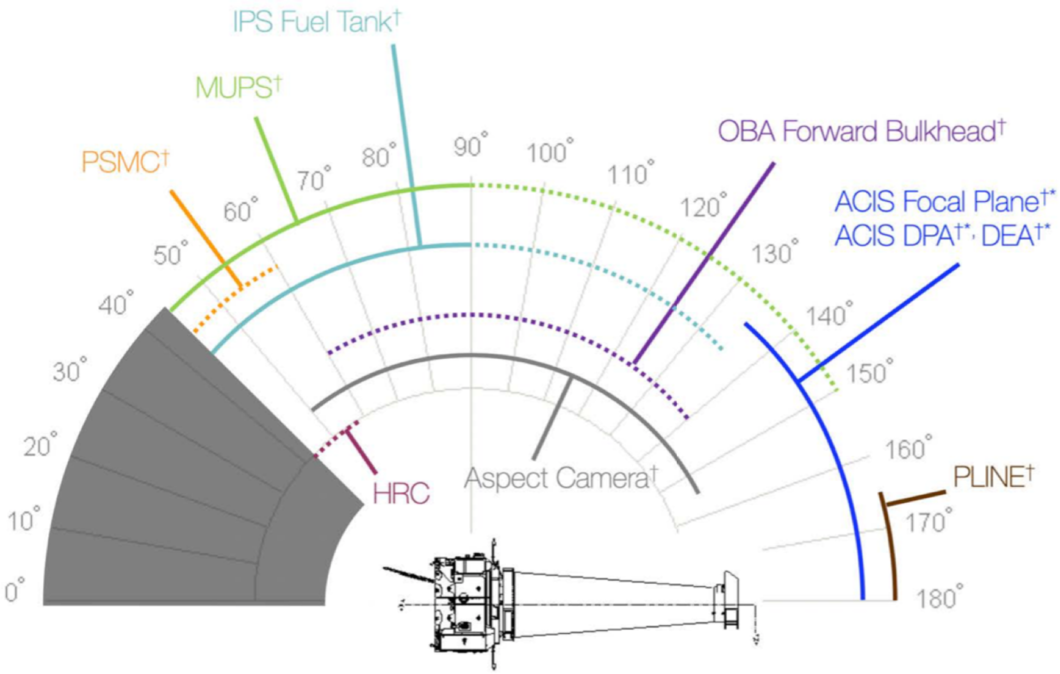


# Chandra Thermal Restrictions

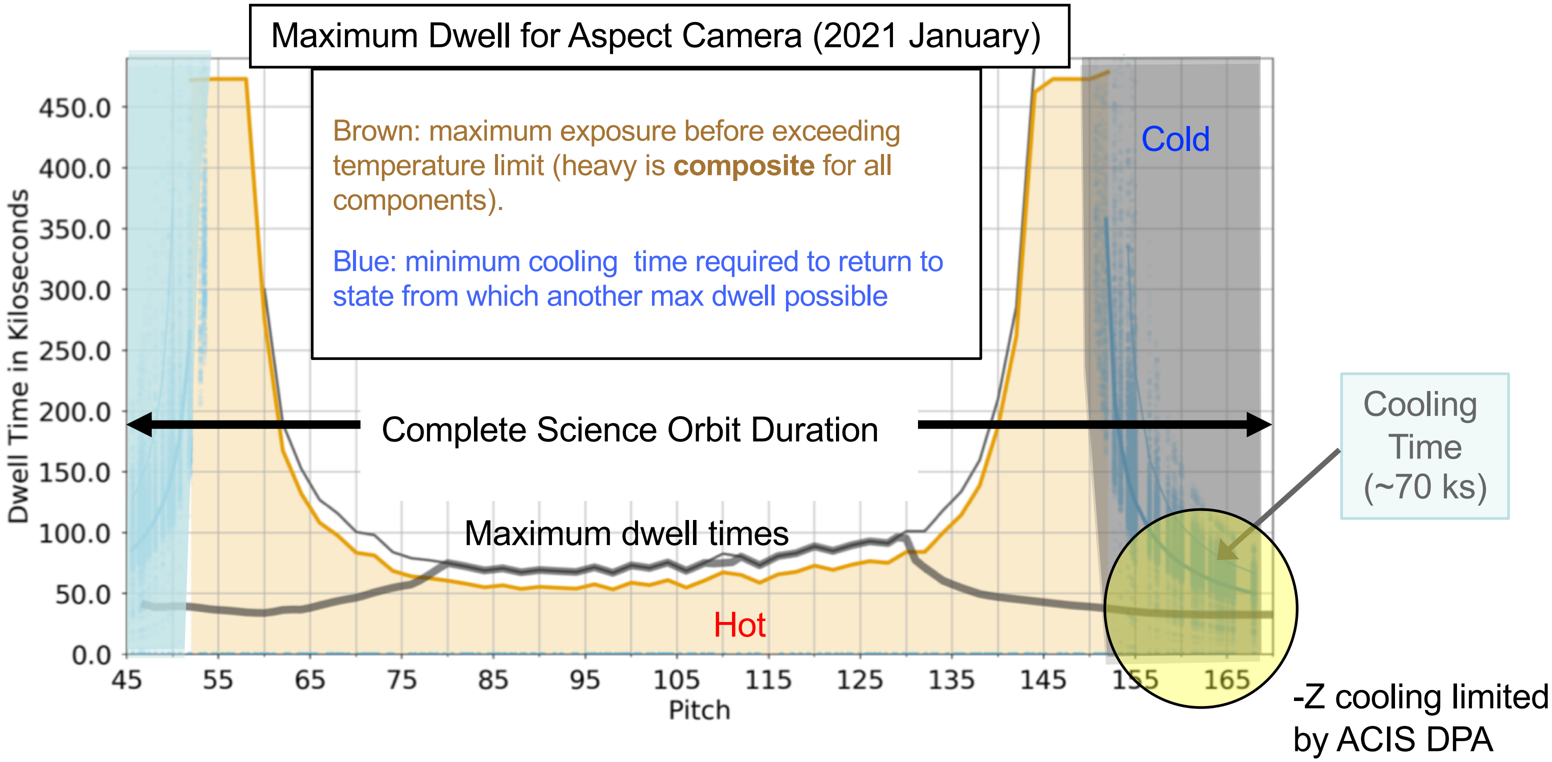
Spacecraft Geometry



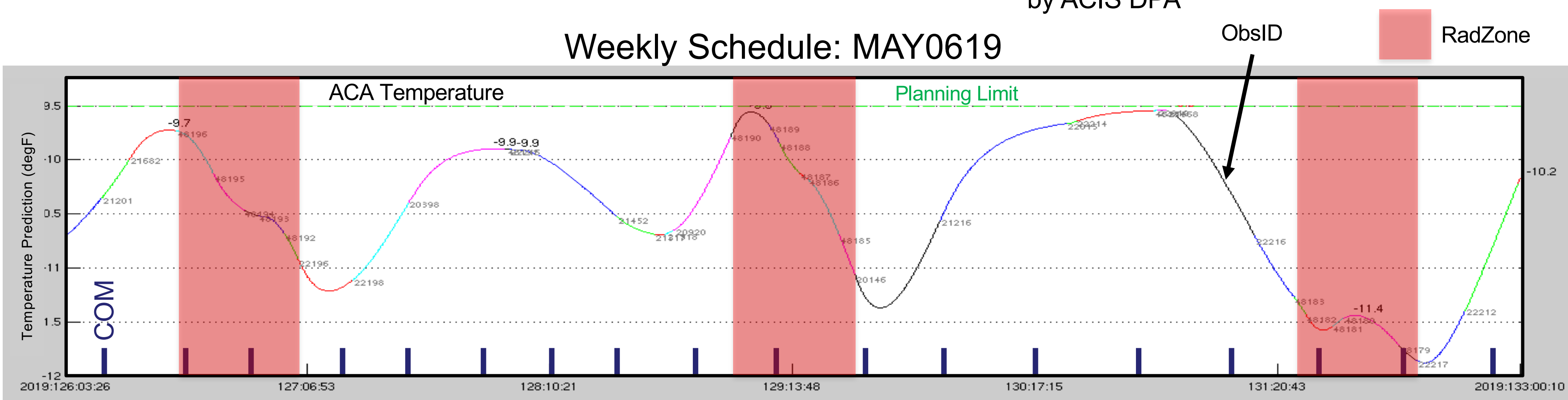

Thermal Restrictions



# Thermal Balance: A Summary

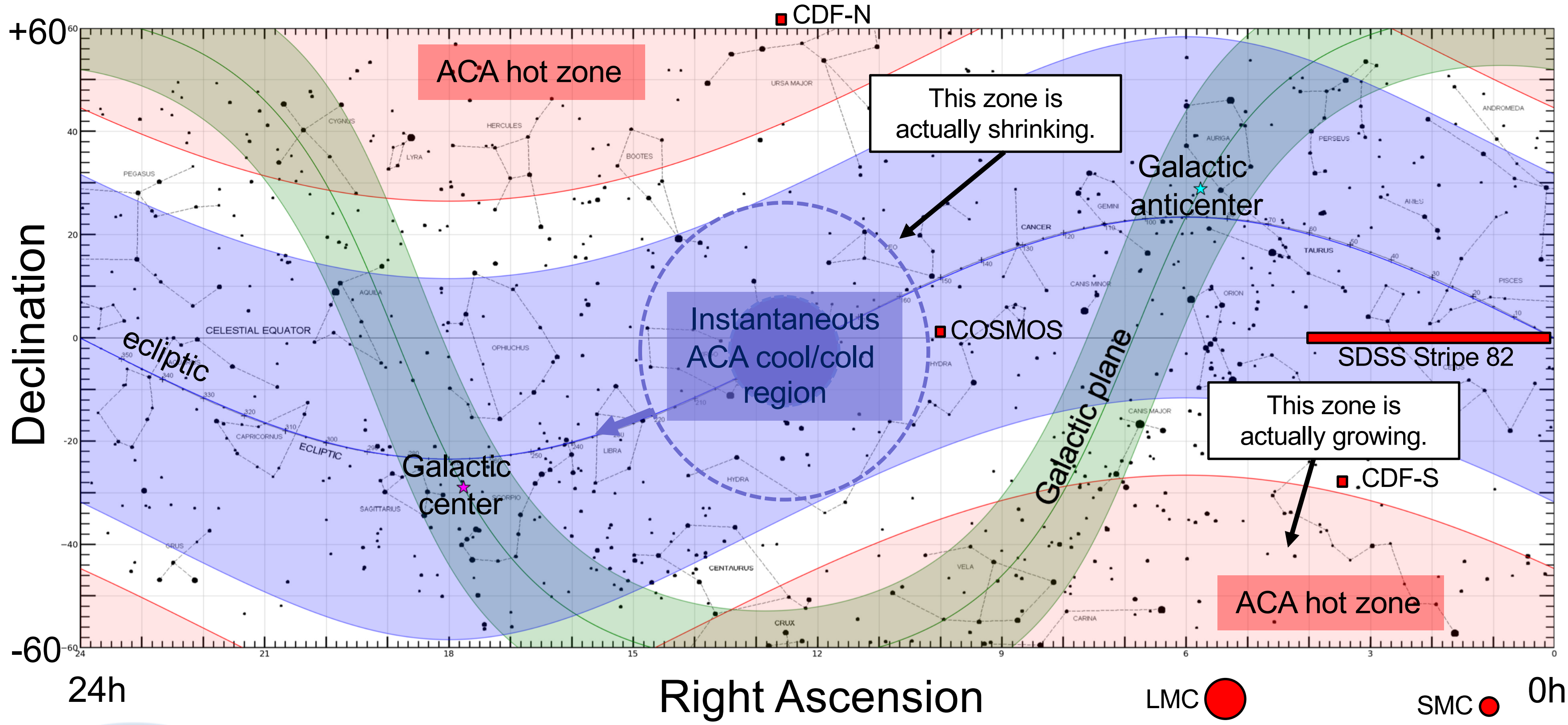


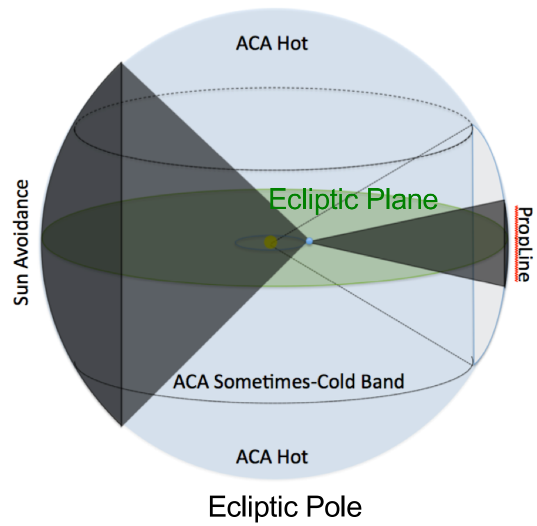

## Weekly Schedule: MAY0619




Note: COM times are illustrative only.

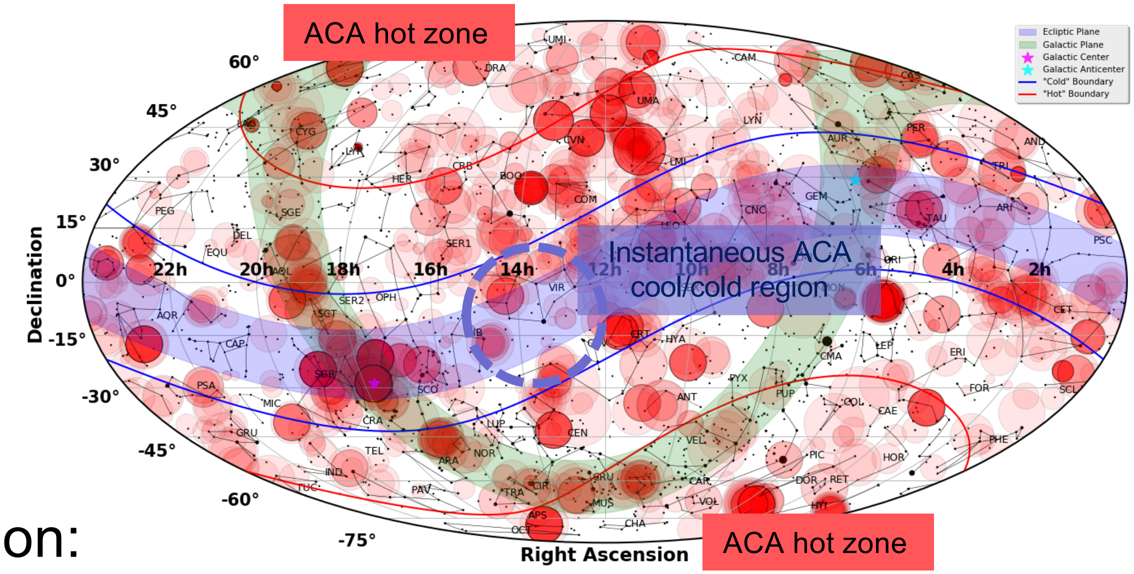
# Constraints: Sky View



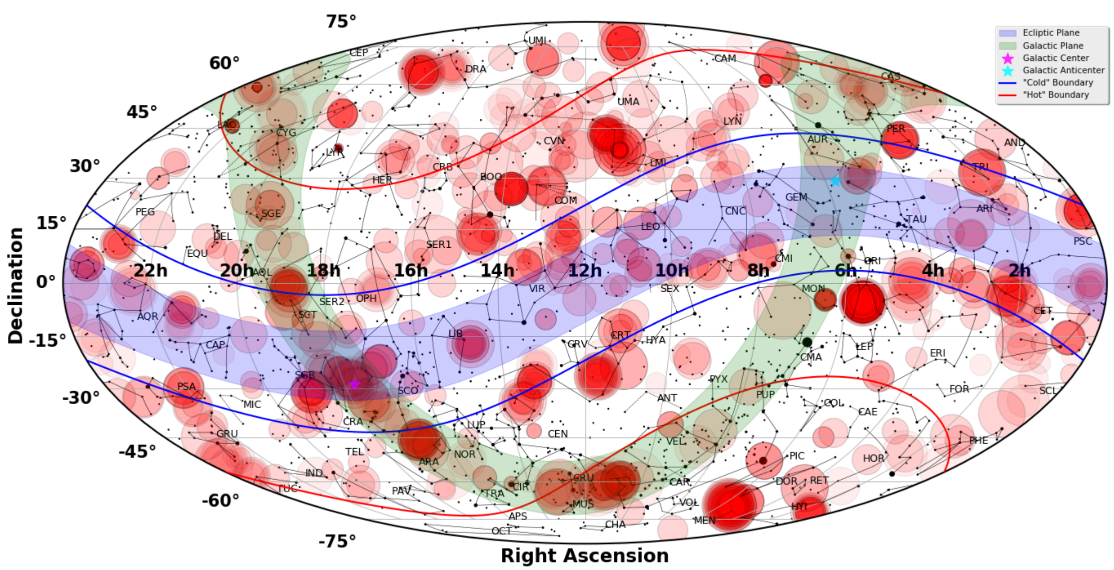




- Sometimes-cool/cold ACA (-Z) region covers large sky area.
  - Many well-known fields can provide some cooling; others always heat the ACA.
  - The cool regions are shrinking and the hot ones are growing.
- In cycle 22, observing time assigned by peer review at high ecliptic latitudes ($|\beta|>55°$)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

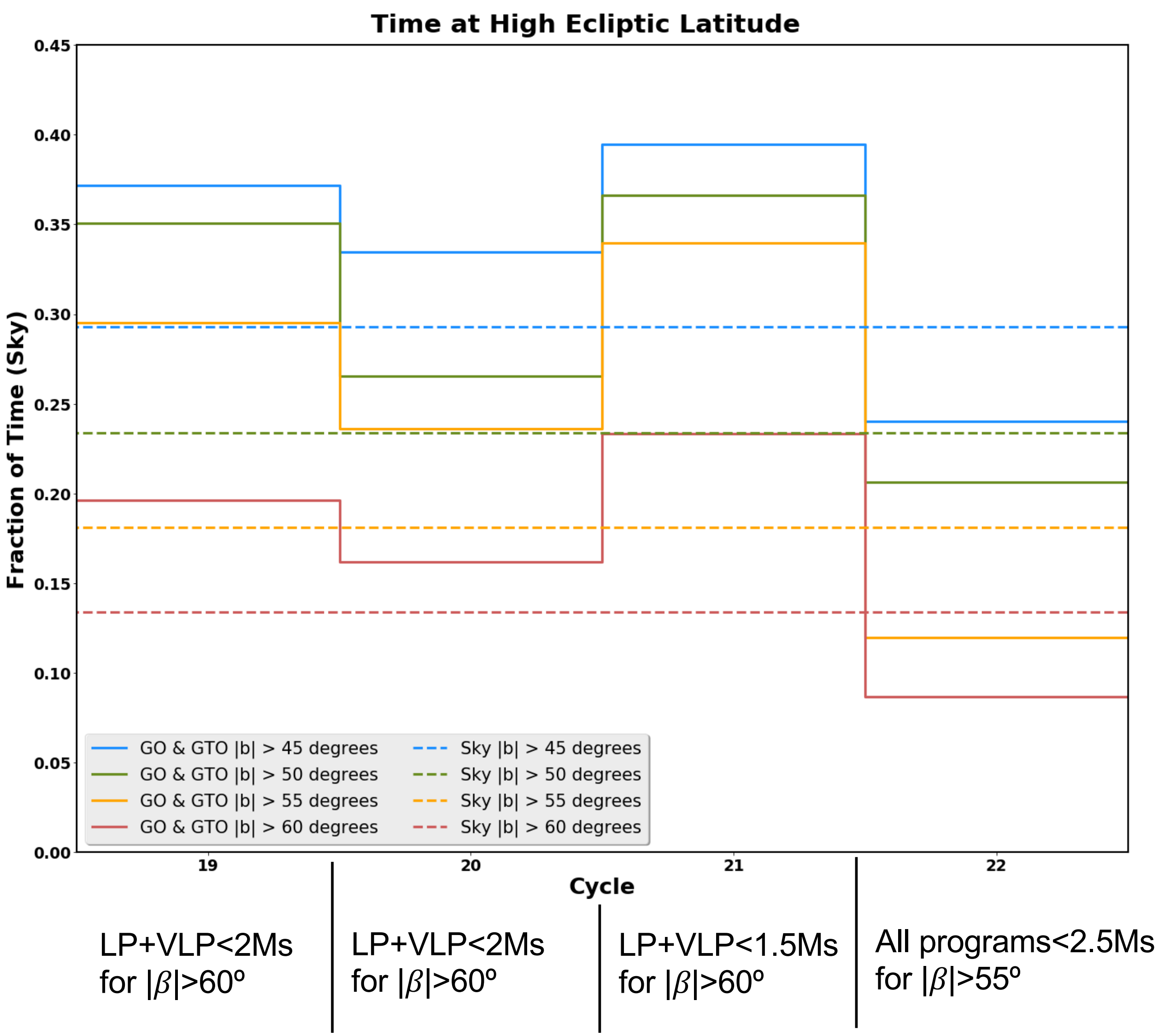
# Target Distribution: Cycle 22




# Target Distribution: observed 2019 Sep – 2020 Oct



# Target Distribution: Cycle 22




- For several cycles, the CXC has been limiting high ecliptic latitude time in large programs only.
- This has net proven adequate: target times at high $\beta$ 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.

# Sample of Significant Planning Efforts

<u>Completed in Cycle 21:</u>

- Sgr A* - 318 ks, including
  - Gravity campaign (4 x 21.6 ks)
  - EHT campaign (4 x 33 ks)
- H1821+643
  - 1 Ms @ pitch angle ~90º
- SNR 0509-67.5
  - 425 ks on SNR in LMC (pitch angle ~90º)
- Eta Carina
  - 285 ks monitoring campaign
- TDE TOO
  - 100 ks Very Fast TOO + 3 x 100 ks follow-ups at 10-15 d intervals

# Sample of Significant Planning Efforts

Coming up in Cycle 22:

- 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 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. Will need special consultation with the ACA team.

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

- A2319, 560 ks
  - Always bad pitch.

# Tool/Process/Limit Updates

## *Spike* scheduling software and LTS development

- Significant work has gone into improving the auto-scheduling software in Spike, to help with building the LTS.

- Out of several algorithms that were looked at, a genetic algorithm approach was found to produce the best results.

- Importantly, the code has been heavily generalized, such that it is robust to changes to the thermal profiles of the various components, and even to adding or removing components that are relevant to building the LTS (e.g., the addition of the "MUPS" component for Cycle 22).

- The code is still under development, but experience has shown that it reduces the workload of building the LTS (during which time the SOTMP member responsible for building the LTS must spend the majority of their time working on it) from 6+ months (when done "by hand" from scratch) to 1-2 months.

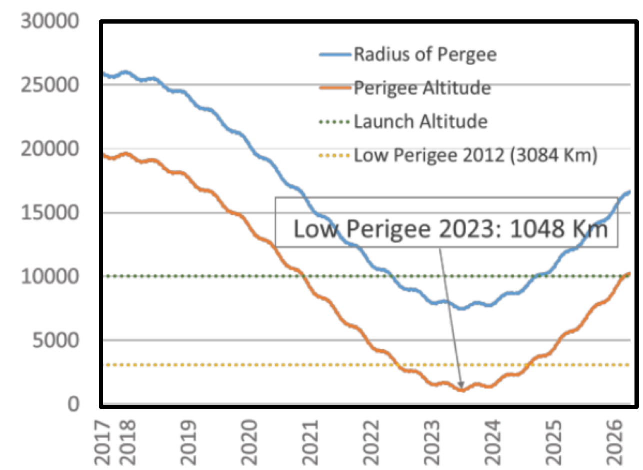
- To do: on-the-fly selection and scheduling of subsets of targets (e.g., all constrained observations); the ability to load in a "starting point" schedule that Spike will attempt to improve upon.

# Tool/Process/Limit Updates

- Worked with CDO and FOTMP to develop and implement a new TOO/DDT Assessment Form (TDAF) to facilitate better communication between SOTMP, FOTMP, and CDO.

- Finalized software to fully integrate the ACA yoshi software(long-term star suitability for use in LTS generation) with SOT MP software to run the ACA yoshi evaluation on LTS, STS, and TOO/DDT targets.

- Starting to address growing importance of momentum management.



# Tool/Process/Limit Updates

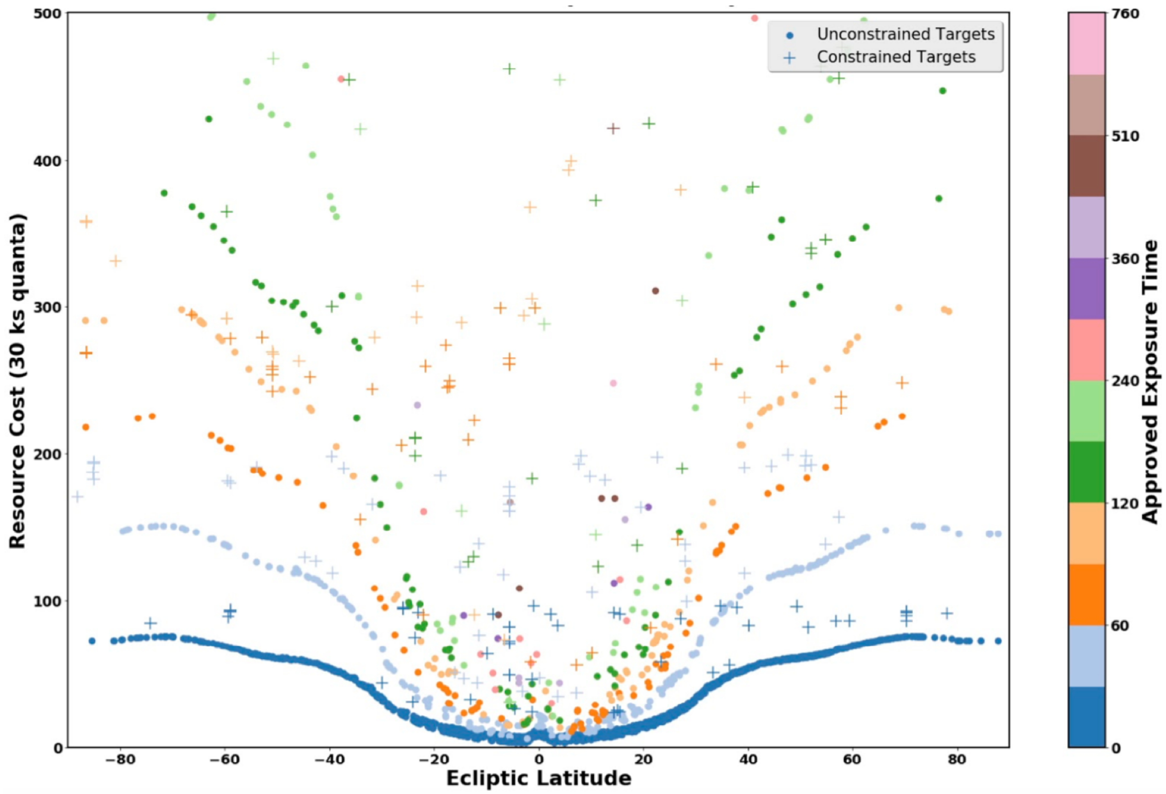
- Continued work on thermal models, and their interface with Spike and LTS development.

- History of recent thermal limit changes

| Model | Date of most recent update | Planning limit relaxations in past year |
|---|---|---|
| ACA | 2020 Sep | -8.5C -> -7.8C -> -7.1C |
| MUPS | 2020 Mar | Added 210F Limit |
| OBA | 2020 Sep | 97F -> 100F |
| Tank | 2018 Sep | 100F -> 105F |
| PLINE | 2020 May | 50F -> 55F -> 50F |
| DEA | 2020 Jul | 35.5C -> 36.5C |
| ACIS FP | 2019 Nov | ACIS-I: -114C -> -112C,<br>ACIS-S: -112C -> -111C |

- Return to single-IRU operation (2020 Jul) has relieved pressure on ACA and recovered ~1yr of thermal aging

# Tool/Process/Limit Updates: Resource costs

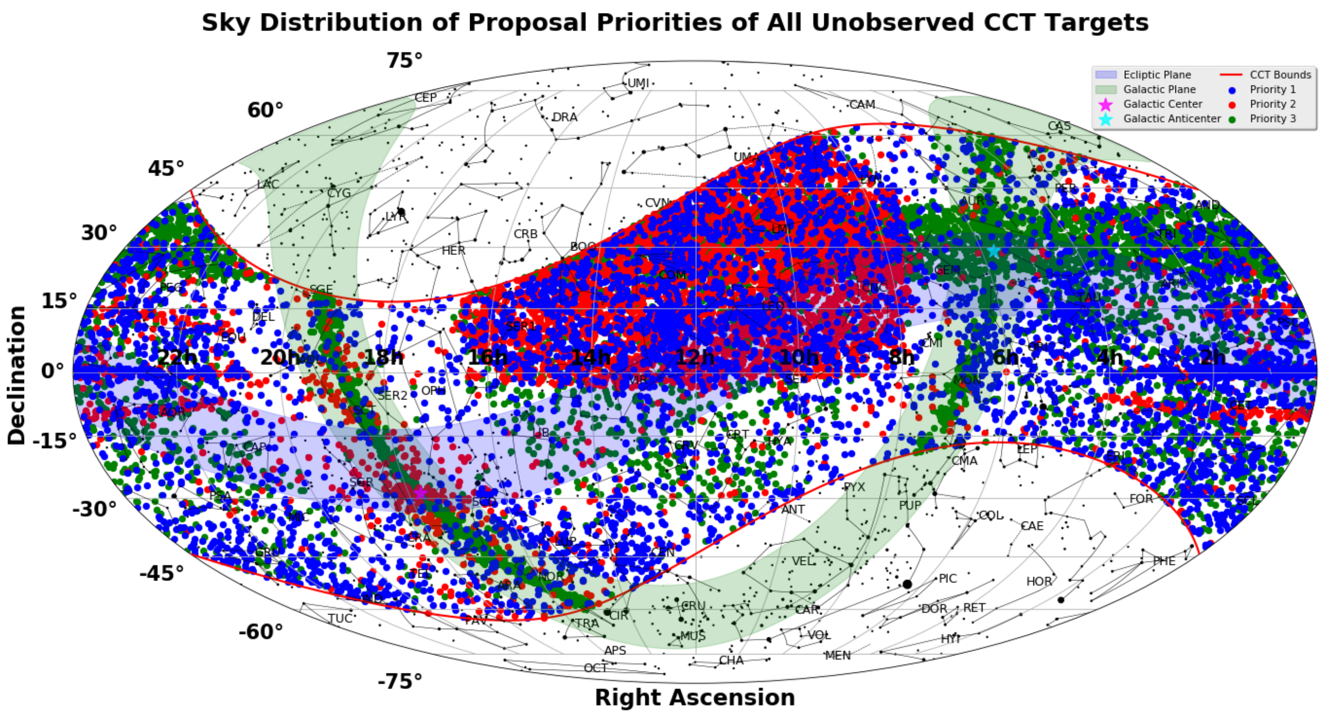


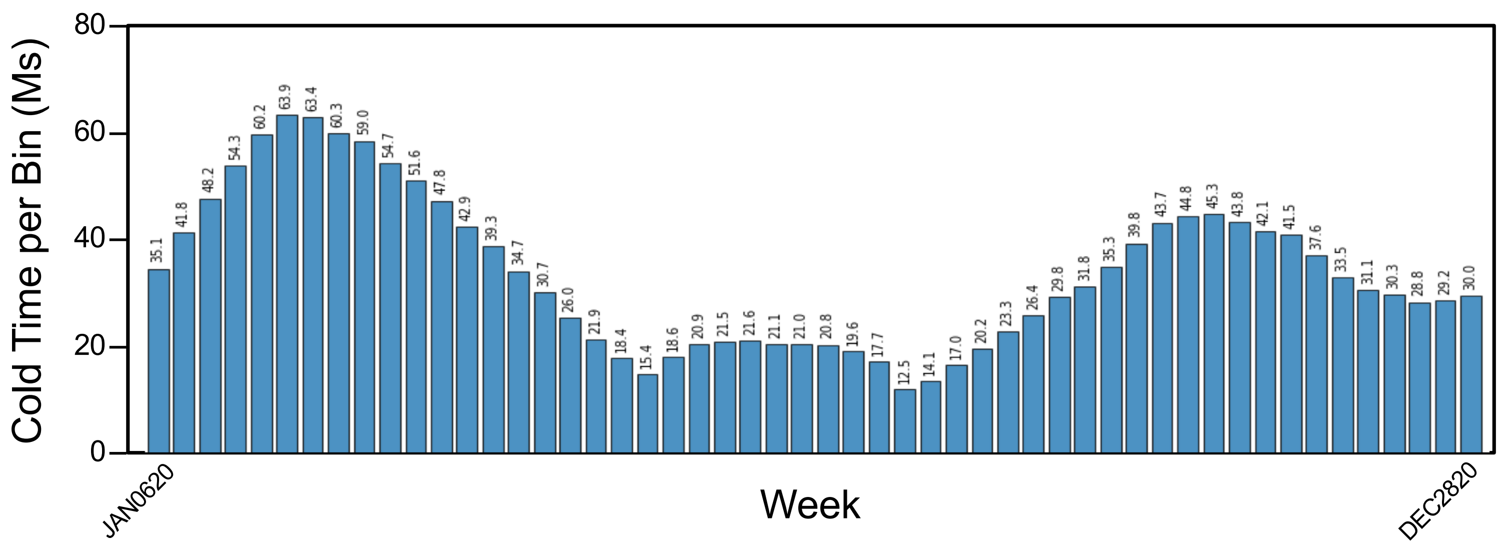

Resource Cost (RC) values for observing programs from *Chandra* Cycles 14-21, calculated using RC formulation for Cycle 22.

- Circles correspond to observations without constraints, for which RC values depend only on ecliptic latitude (X-axis) and exposure time (color bar at right) in units of 30 ks segments (rounded up to nearest integer).
- 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

# 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

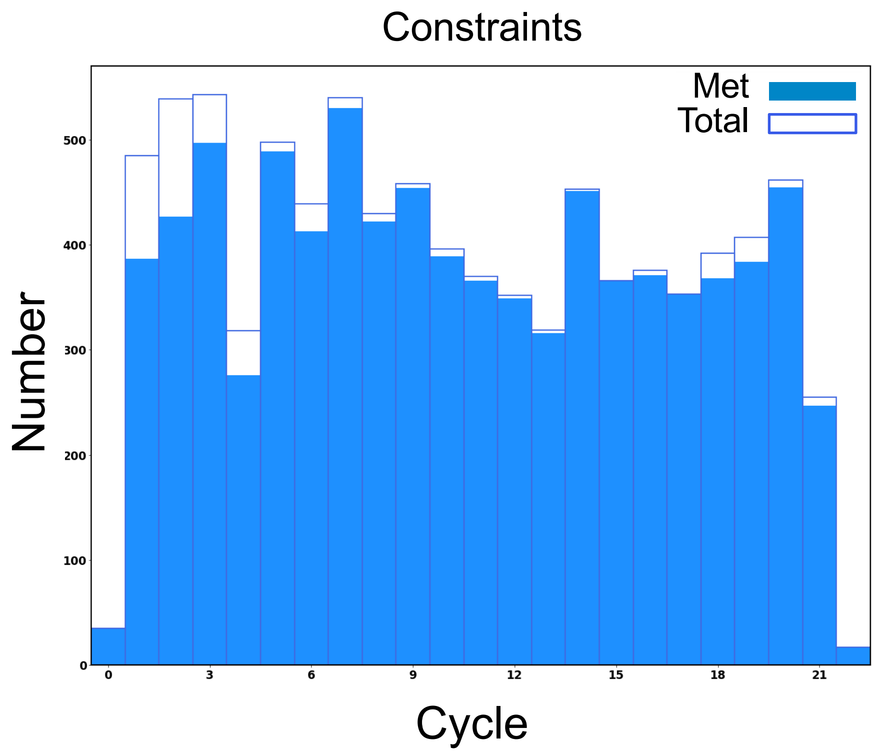
10 ks ≤ t ≤ 35 ks; |b| < 40º

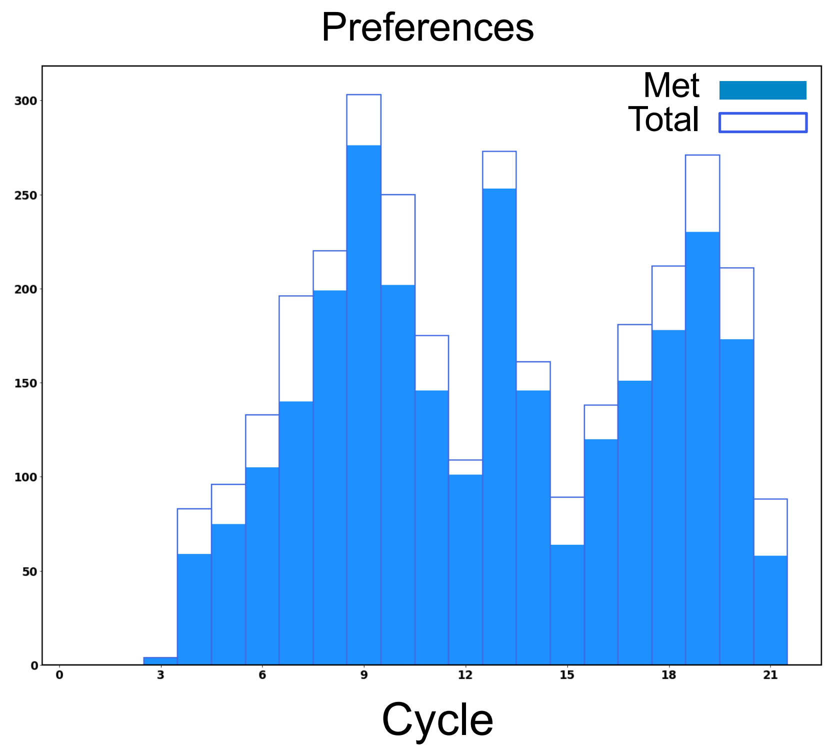
- Includes:
  - ~19,000 targets
  - ~400 Ms in time

- Adequate cooling time in any week

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

# Constraints and Preferences

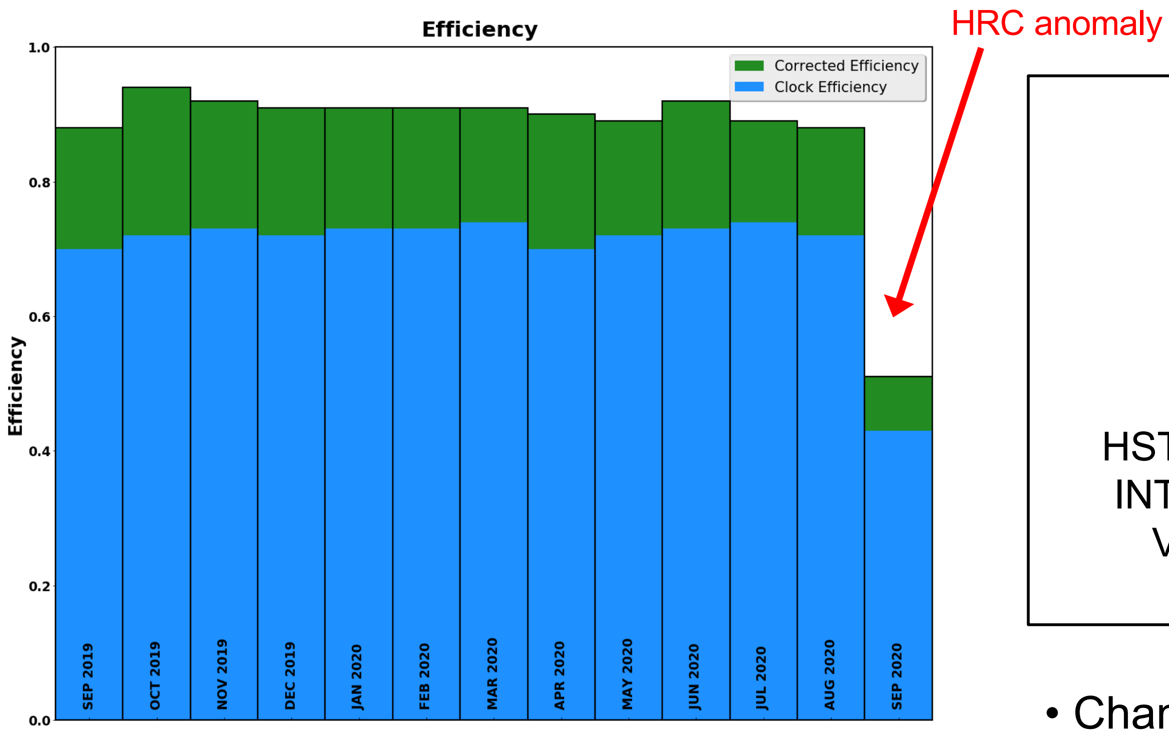



- Continue to meet observing constraints successfully with high observing efficiency.
- *Through cycle 21:* Continue to support significant number of observing preferences.
  - Ability to meet these is decreasing due to spacecraft constraints.

- Programs with preferences for pointing/ offset adjustments based on roll are becoming becoming problematic:
  - Can't be used as pool targets.
  - More importantly, star selection can be a major complication.
  - Must now be specified at proposal time and are evaluated during LTS development

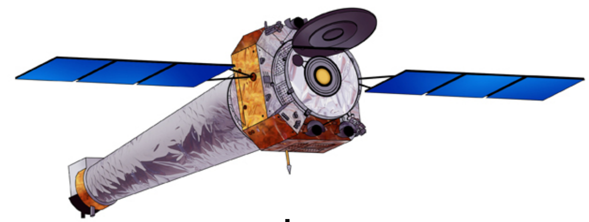
# Observation Scheduling




From Sep. 2, 2019 - Oct. 5, 2020:

- Scheduled: 996 observations (24.1 Ms)
- Executed:
  - 59 TOO observations (1966 ks)
  - 65 DDT observations (1107 ks)
    - ✧ interrupted 8 operating loads for TOO/DDT support

**Coordinated Observations**



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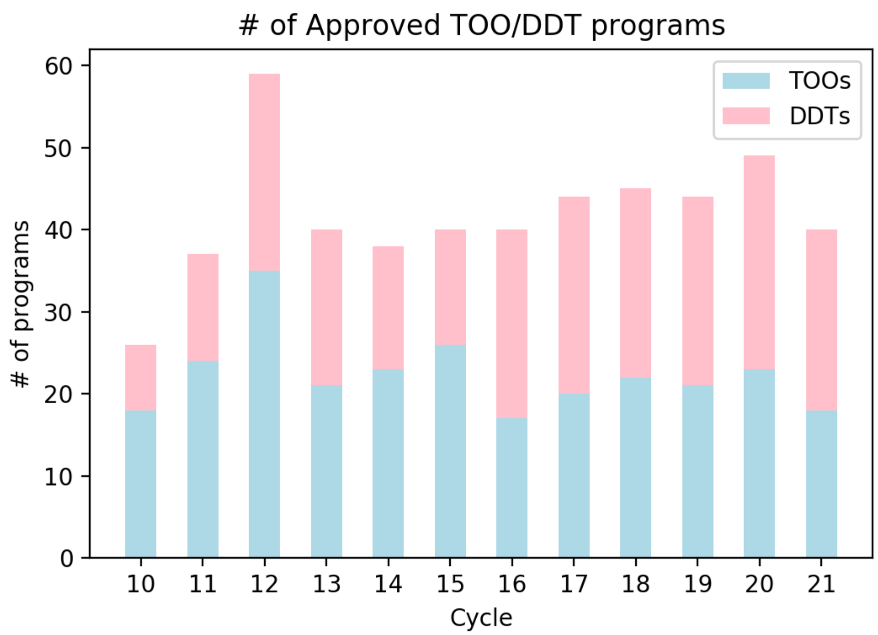
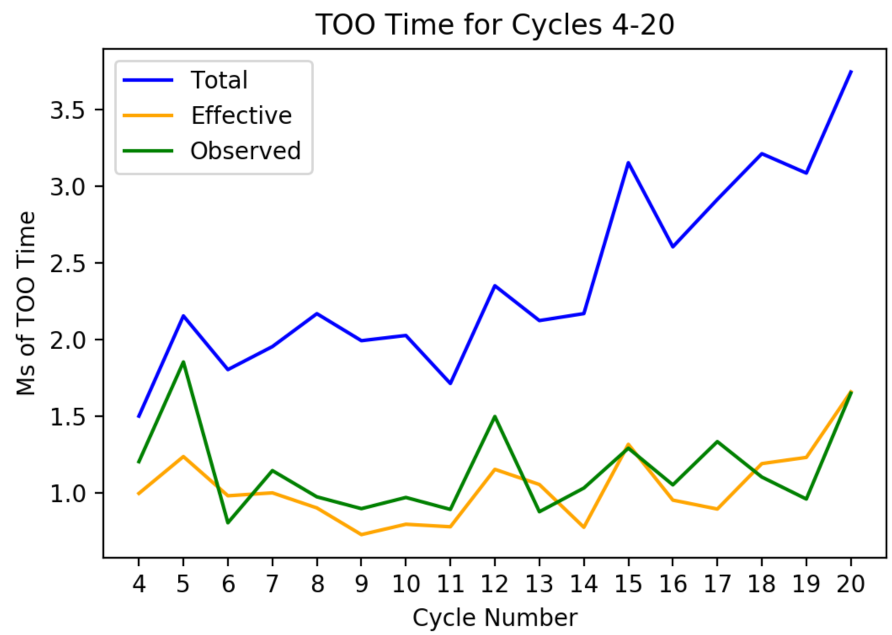
HST, VLA, NuSTAR, Swift, XMM, Astrosat, INTEGRAL, NICER, EHT, ATCA, Gemini, VLTI/GRAVITY, Effelsberg, eROSITA

- Chandra Coordinations (2019Sep-2020Oct):
  - Constraints: 13 observations (359 ks)
  - TOO/DDT coordinations: 26 (725 ks)
  - Non-specified/Unofficial: 16 (360 ks)
  - Preferences: 11 observations (310 ks)

⇒ These represent major efforts. As of cycle 22, only constraints are permitted, and constraints are allowed for coordination with any facility.

# TOO/DDT Observations: Historical Performance



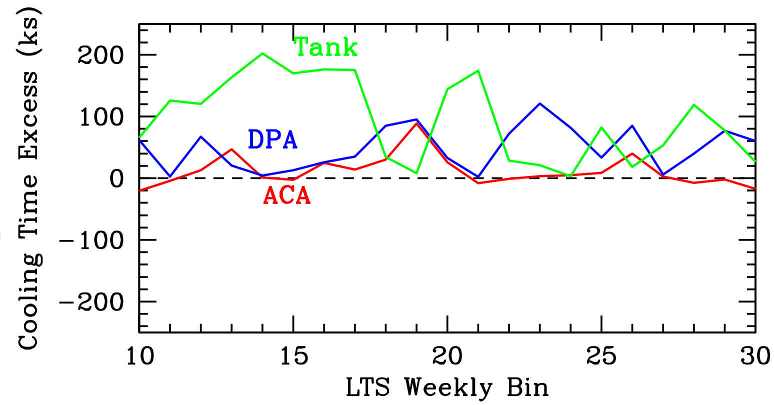




Historical TOO/DDT performance has been very steady despite evolution of thermal constraints over more than a decade.

- This has been done by continued development of tools and procedures, and this process continued 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

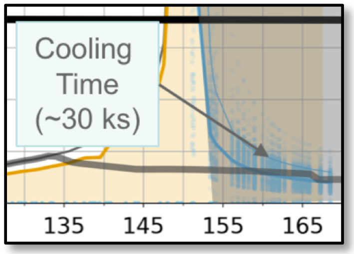
Coordinations

- 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 ~10 hours beyond historical times in order to pre-cool.




- Need to have well-defined and configured programs in advance.
  - Changes “on the fly” delay approval and planning process.
- Anti-TOOs are TOOs
  - Pulling a TOO or its follow-up after scheduling requires the same effort as starting a new TOO.

- Approach to TOO follow-ups has been changed effective cycle 22
  - TOO follow-up observations were formerly classified as constrained observations.  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<br>----<br>Rebuild Prelim* | ACA Pre-review of Prelim<br>----<br>Rebuild Prelim* | Deliver Prelim to SOTMP<br>----<br>SOTMP Review | |
| Schedule Review | SOTMP Delivers Final ORL<br>----<br>FOT Builds Final Schedule | FOTMP Builds Official Loads<br>----<br>FOTMP Review | Loads Released for Review<br>----<br>Load Review | Subsequent Load Builds and Load Reviews, if necessary. | | |
| Schedule Running | LOADS ONBOARD AND RUNNING<br>(Planner who built loads is on-call, performing all FOTMP reviews, and already starting the next schedule's first week) | | | | | |