Prospects and Issues for a Fifteen Year Chandra Lifetime

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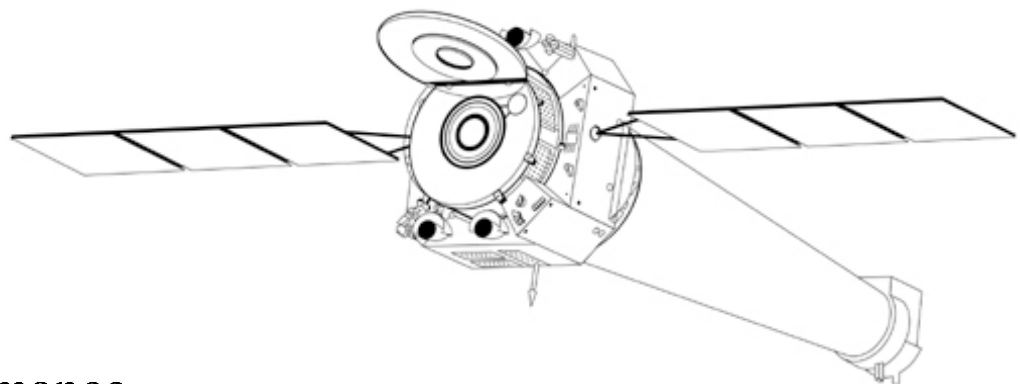
FOT Mission Planning

Introduction

Viability of the Spacecraft for a 15 year Mission will be determined by:

- **Vehicle Health**
  - Hardware Status
  - Thermal Status
- **Orbit**
- **Science Return**
  - Instrument Performance
  - Constraint Evolution



Hardware Status

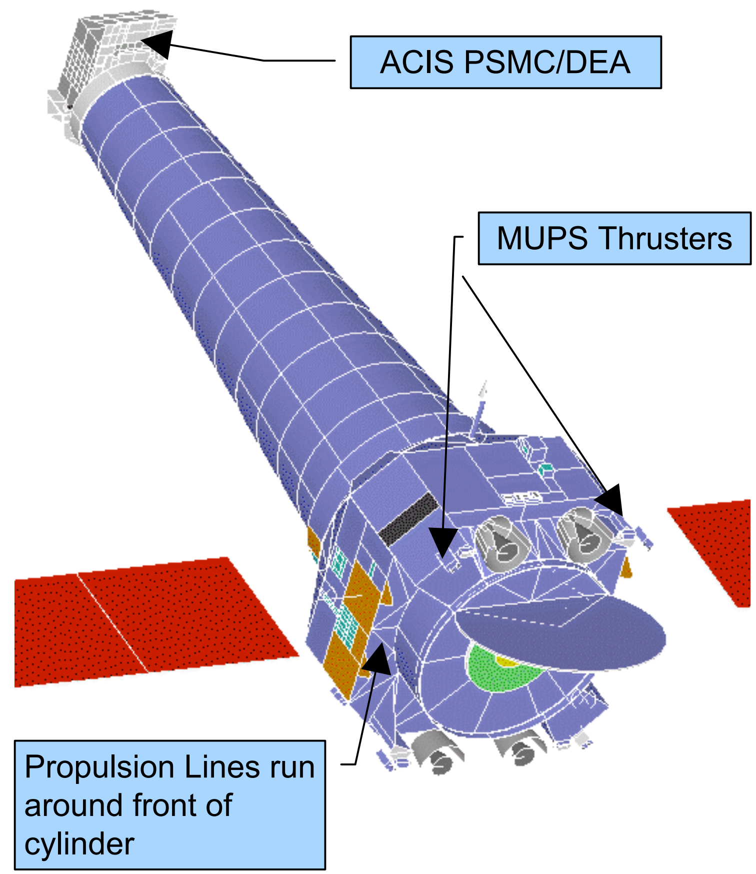
Subsystem						Status
CCDM	CTU IU XMTRA	PCRCTU OBC XMTRB	EPRCTU EIA PA A	SIRCTU USO PA B	TSRCTU RCVRs LGAs	
Electrical Power	PCU	Arrays	Batteries	PSU		
Flight Software	Memory	Speed	Errors			
IEPHIN	EPHIN	EIO				• Temp exceeding original unit survival limits. No signs of performance degradation. Unit power supply in current-limited state when hot.
Mechanisms	SEA A SIM Mot SIM Table	SEA B Foc Mot FA	MCEA HG Mot HETG	MCEB LG Mot LETG		• Microswitches that detect grating insertion and retraction failed. Now controled by FSW.
Pointing Control	SPE IRUs FLCA	IOE FSSs VDE	CPE CSSs RWA	ADE ACA		• A switch from IRU1 to IRU2 was performed to preserve the life of IRU1 Gyro 1.
Propulsion	Thrusters	Fuel	Lines	Valves		• Propulsion line freezing concern due to thermal gradients on spacecraft bus. Limiting obs. attitudes; new safing monitor is active.
Thermal	SEA Thrmosts Sensors	IP SEA Heaters	MLI Coatings Radiators			• -Z degrading faster than pre-lauch estimates, causing unit temps to be near or exceed original qual and survival temps.

Legend

- No performance issues or open anomalies
- Minor Issue – Addressed with operational change - No single point failures
- Minor performance issue – may be open anomalies or operating on redundant units – may have single point failure
- Major performance issue – anomalies with system impacts – known single point failures

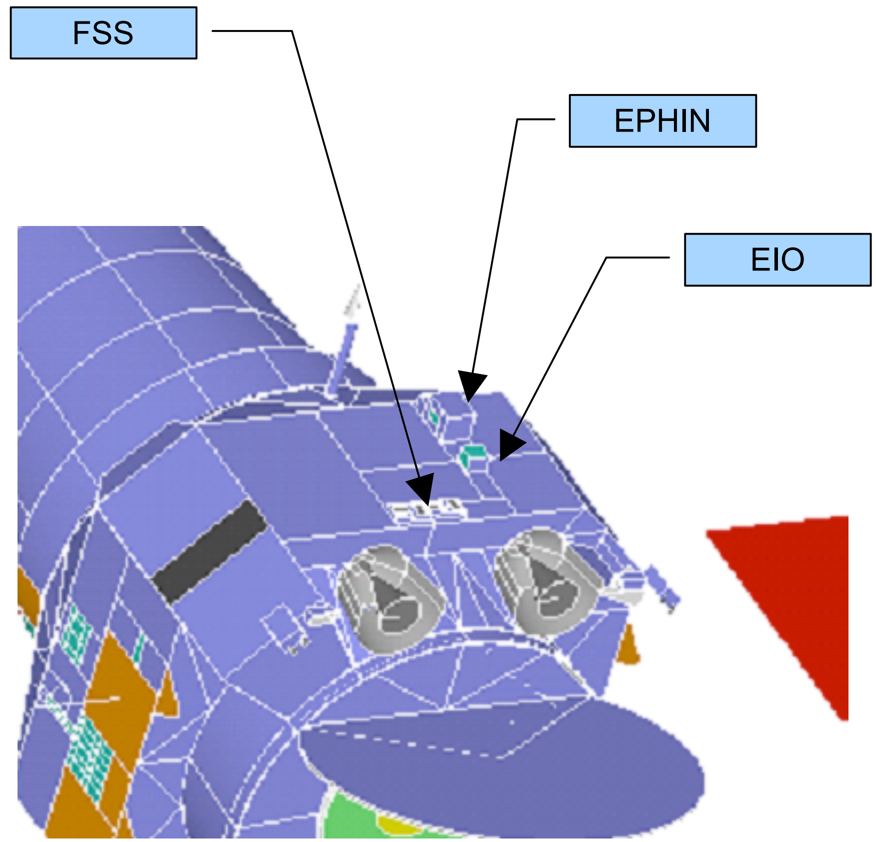
Thermal Concerns
Forward Sun

- **Area of Concern**
  - Forward sun (45-75 deg sun angle)
- **Units affected**
  - Propulsion Components
  - ACIS PSMC/DEA Power Supply
- **Outlook**
  - Continued temperature increase expected, rate of increase expected to slow
- **Course of action**
  - Limit duration of momentum unloads
  - Cold-soak thrusters before momentum unloads
  - Limit duration or number of ACIS chips used for observations at far forward sun
- **Observing Impact**
  - Duration limits on some ACIS observations



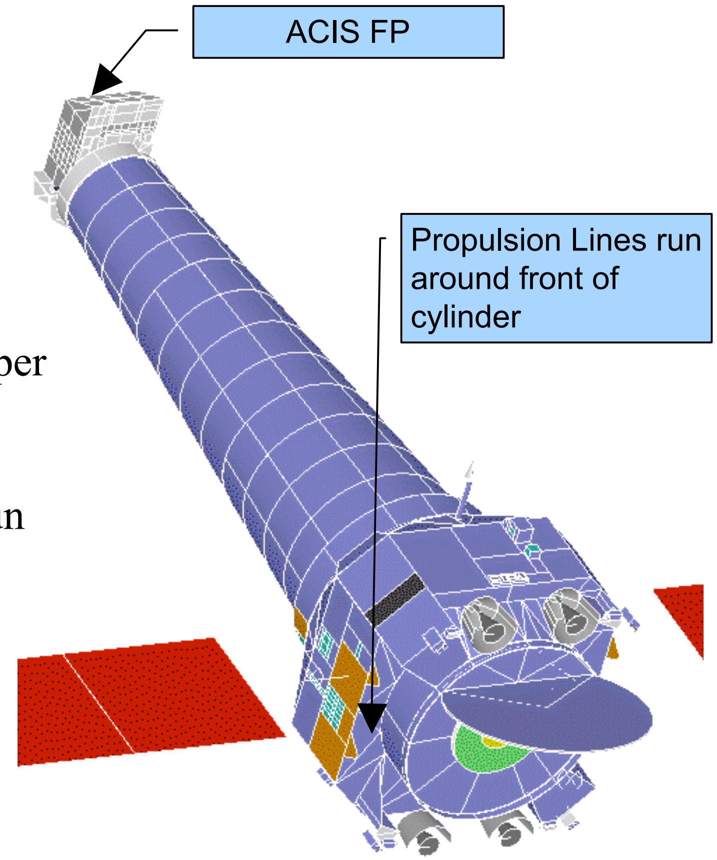
Thermal Concerns
Normal Sun

- **Area of Concern**
  - Normal sun (75-130 deg sun angle)
- **Units affected**
  - Fine Sun Sensor
  - EPHIN & EIO
- **Outlook**
  - Continued temperature increase expected, rate expected to slow
  - FSS thermal time constant too fast to entirely avoid hot temperatures
- **Course of action**
  - Avoid long normal-sun and off-nominal roll observations
  - Close monitoring for unexpected trends
  - Investigate operation w/o FSS
- **Observing Impact**
  - Segmented observations
  - Difficulty meeting some science constraints

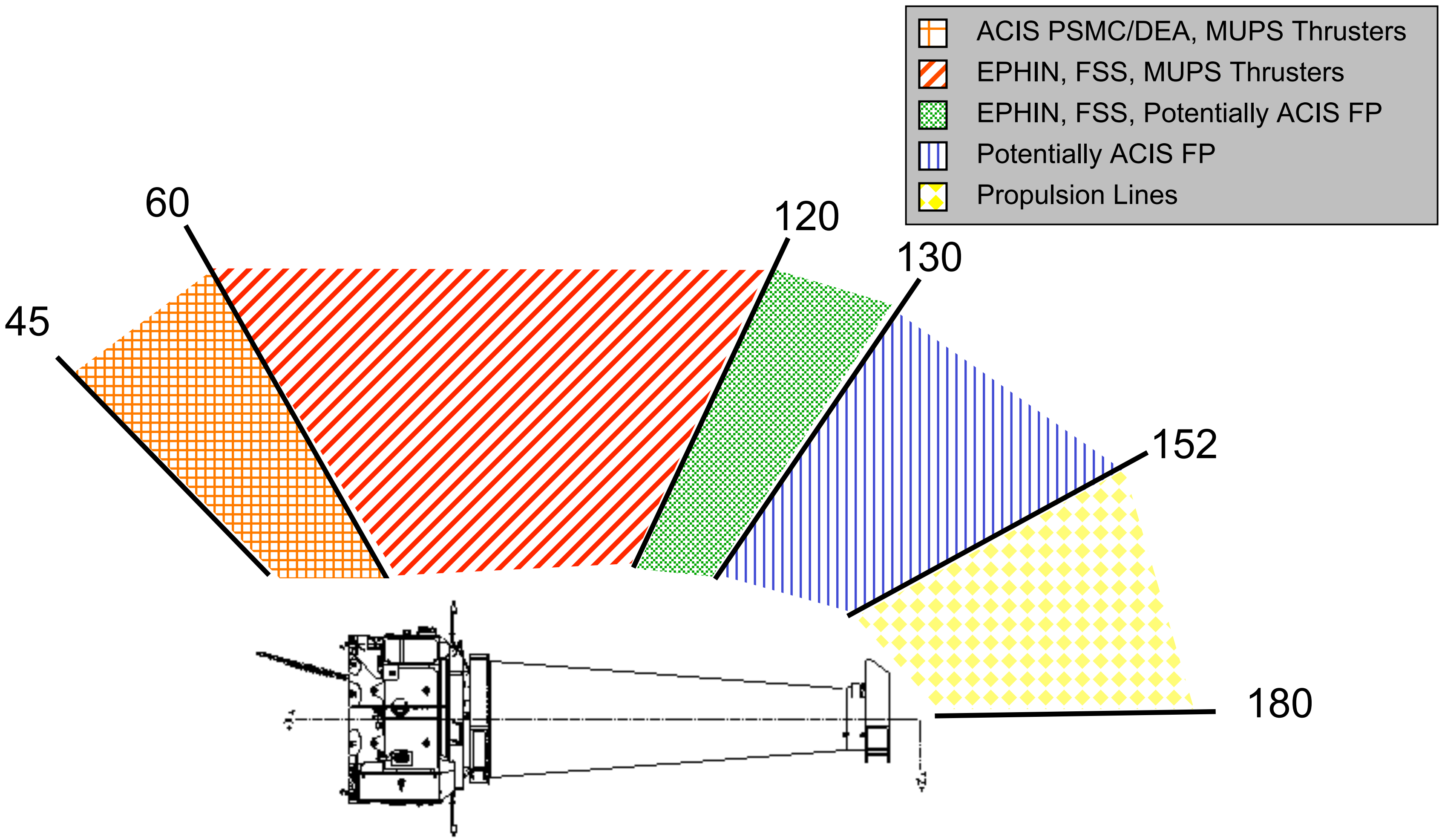


Thermal Concerns
Tail Sun

- **Area of Concern**
  – Tail sun (135-180 deg sun angle)
- **Units affected**
  – ACIS FP
  – Propulsion Lines (PLINE) - COLD
- **Outlook**
  – Continued temperature increase for ACIS FP
  – PLINE region expected to get smaller, but deeper
- **Course of action**
  – No observations at 170-180 deg sun pitch
  – Strict limits on observations at 152–170 deg sun pitch
  – ACIS FP mitigations under investigation
- **Observing Impact**
  – Reduced cooling ability for normal sun units
  – Unable to meet small number of window or coordination constraints
  – Reduced gain calibration accuracy for some ACIS observations



Temperature Constraints vs Sun Pitch

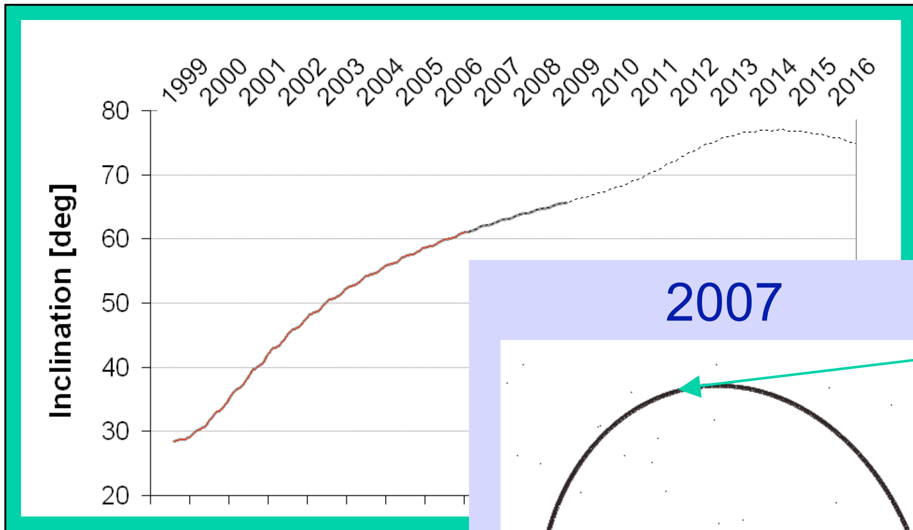


Vehicle Health Summary

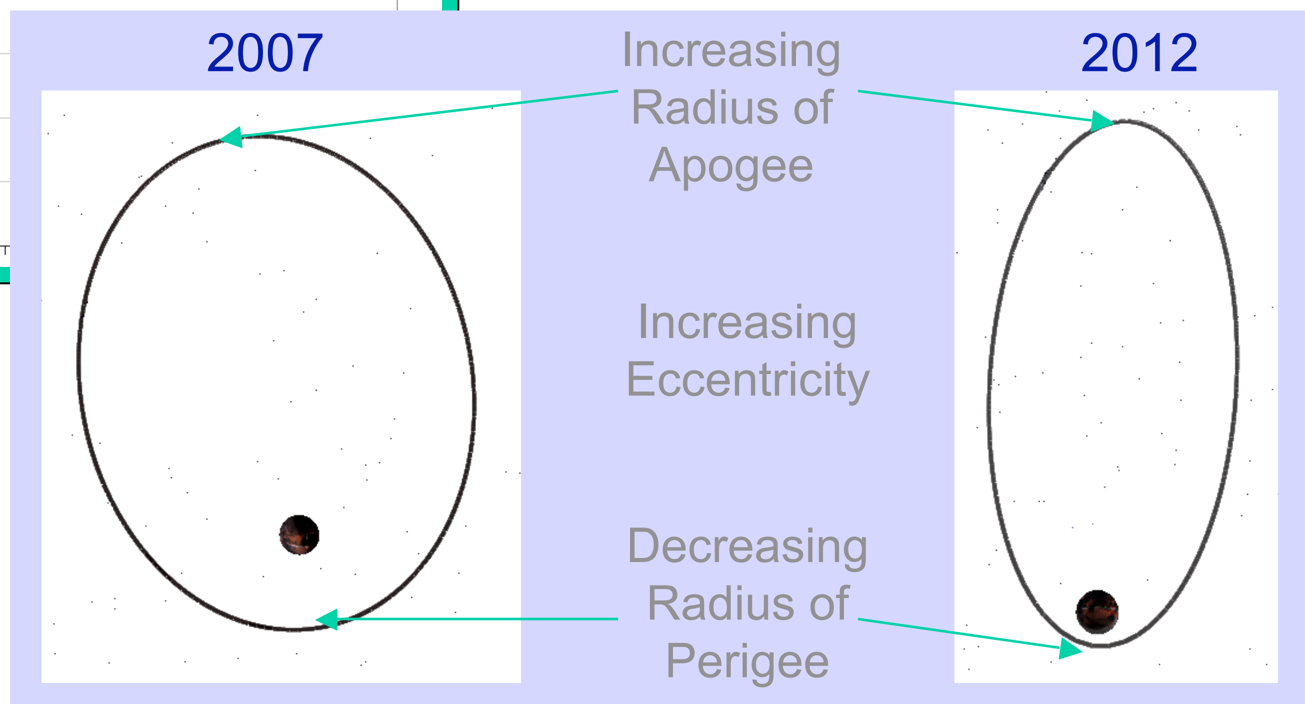
- **Hardware is in good condition and in a favorable position to support the 15 year mission**
- **The protective thermal surfaces on the –Z-side (sun side) have been slowly degrading over the mission, but at a rate higher than expected pre-launch**
- **It is expected that they will continue to degrade, but at a slowed rate**
- **Components throughout the –Z-side have been and will continue to be impacted**
- **Thermal impacts have been successfully mitigated by adding scheduling constraints**
- **It is expected that scheduling constraints will continue to mitigate most –Z-side heating effects**
  - **Fine Sun Sensors are the only currently predicted exception**
    - Important component of safing system, but not used for control in science modes
    - Efforts underway to scope changes required to operate without FSS

There are currently no vehicle health concerns that jeopardize the 15 year mission

Orbit Changes



Perturbations caused by the non-spherical shape of the Earth, the Moon, the Sun, Jupiter, and other forces change the shape of Chandra's orbit.



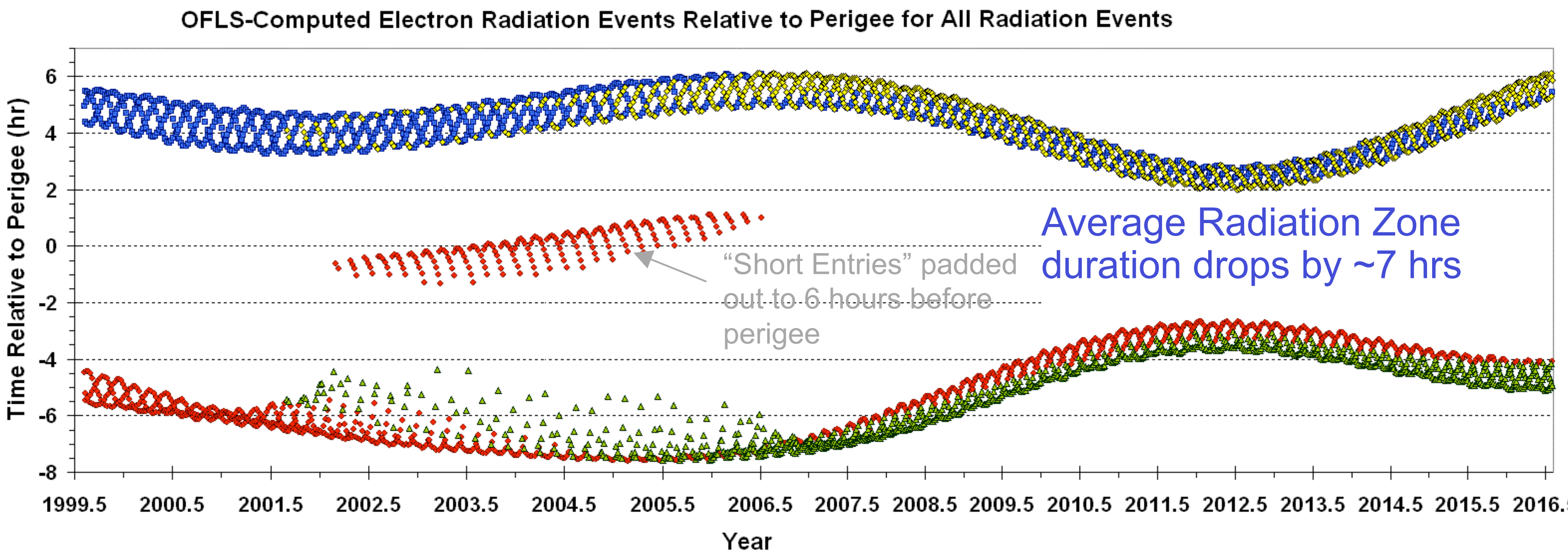
Between now and 2012 the orbit will tilt up toward the Earth's poles and elongate

Impacts

- Eclipse Times
  - No eclipses that the vehicle cannot handle
  - Eclipse seasons will get longer, but will not impact observing time
- Communications
  - Largely unchanged, no observing impact
- Radiation Zones
  - Low perigee altitude and increasing inclination will change radiation environment in the radiation zone
- Perigee Attitude Planning
  - Low perigee altitude will cause increased gravity gradient torques, which can lead to unacceptably high system angular momentum
  - Low perigee altitude and changing radiation zones will reduce flexibility in attitude selection through perigee
  - Reduced flexibility through radiation zones may reduce ability to perform constrained or long duration observations

Radiation Zones

Moving faster through perigee and transiting a different part of the Radiation Zones causes the predicted duration of the radiation zones to decrease



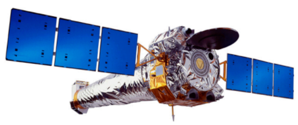
Times DO NOT include ACIS Calibration "pad time" of ~10ks

Impact of new radiation environment must be further investigated

Perigee Attitude Planning

- **Perigee Attitudes (attitudes used during Rad. Zone passage) are used to**
  - Execute Engineering activities
  - Prepare for the next orbit of observations
- **An advantageous perigee attitude must**
  - Meet all spacecraft pointing constraints (Sun, Earth, Moon, X-ray sources)
  - If in eclipse, be within +/- 1 degrees of normal Sun and nominal roll
  - Minimize (maintain) system angular momentum (attitude planning or unload)
  - Thermally prepare for the next orbit of observations, while meeting all thermal constraints
  - Keep the Earth out of the ACIS Radiator field of view
  - Minimize duration of the maneuver to the first observation
- **Momentum Planning will begin to dominate this list**
- **Available attitudes will be further restricted by longer eclipse seasons and the angular size of the Earth through perigee**

Decreased flexibility in perigee attitude selection decreases the ability to prepare for the next orbit, reducing ability to schedule some observations



Summary of Orbit Impacts

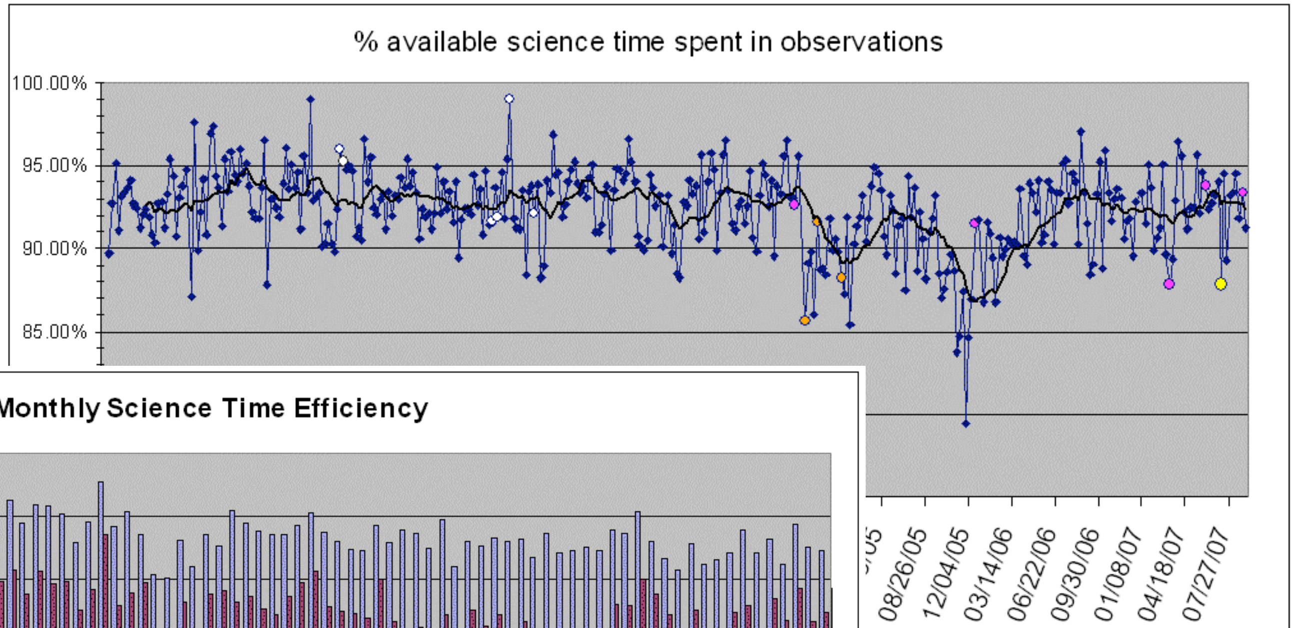
- **The evolving orbit will support a 15 year Chandra Mission**
- **Radiation zones may become shorter**
  - Requires further study
  - Potential to gain science time every orbit
  - May require executing some engineering activities during science time
- **Perigee attitude planning will become dominated by momentum accumulation, eclipse requirements and Earth avoidance**
  - Will likely decrease ability to prepare for next orbit, and thus ability to schedule observations in restricted regions
  - Likely to increase ACIS Focal Plane (FP) temperatures during and following perigee passages
    - May require extending CTI time
    - May cause warm ACIS FP temperatures (decreased gain calibration accuracy) on observations immediately following radiation zone

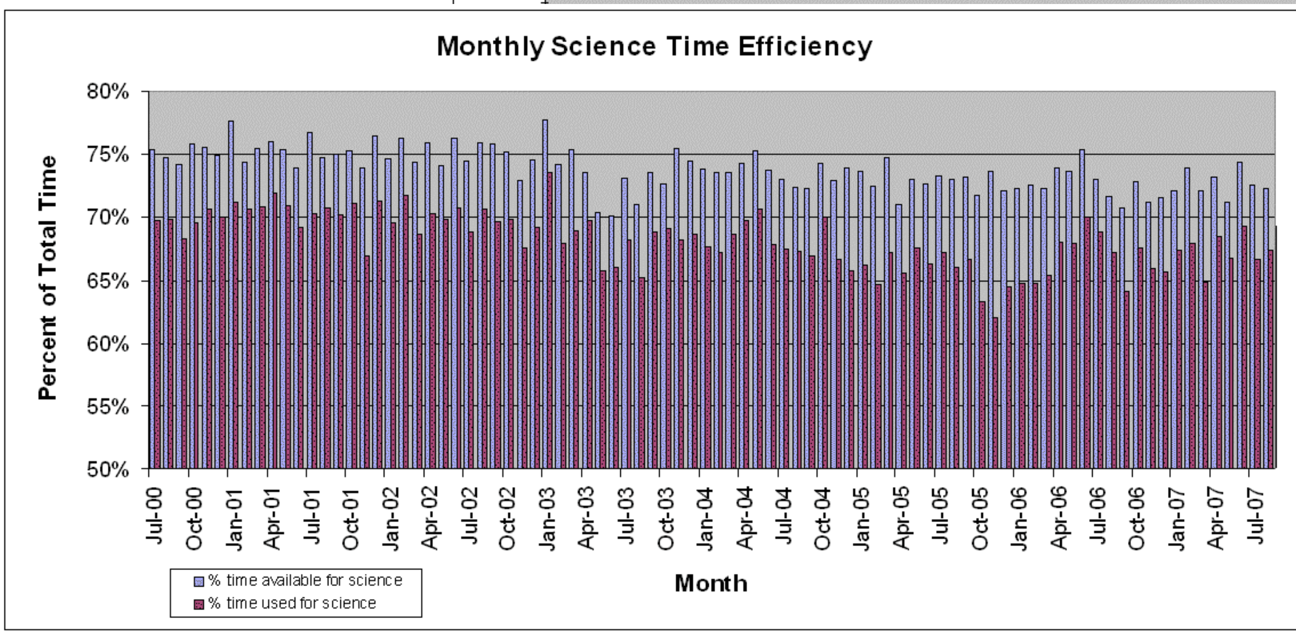
Scheduling Constraints

- **Constraints are used to**
  - Protect the vehicle
  - Ensure each observation is scheduled for maximum science quality
- **Scheduling constraints impact how observations and engineering activities are scheduled**
- **Constraints can impact scheduling in four ways**
  - Time used for science observations
  - Target availability
  - Mission Planning effort (Science Team and/or Flight Team)
  - Schedule complexity
- **Some constraints will change with time**
  - Unchecked, constraints can and will over-constrain scheduling over time
  - When scheduling becomes over constrained
    - Observations are split and sometimes cannot be performed as requested
    - The percent of available time used for science declines

Observing Efficiency

In 2004 -2005, scheduling became over-constrained and observing efficiency declined



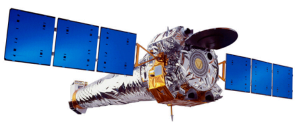


Relaxing constraints and re-working scheduling techniques on the science team and flight team has allowed efficiency to recover

NORTHROP GRUMMAN

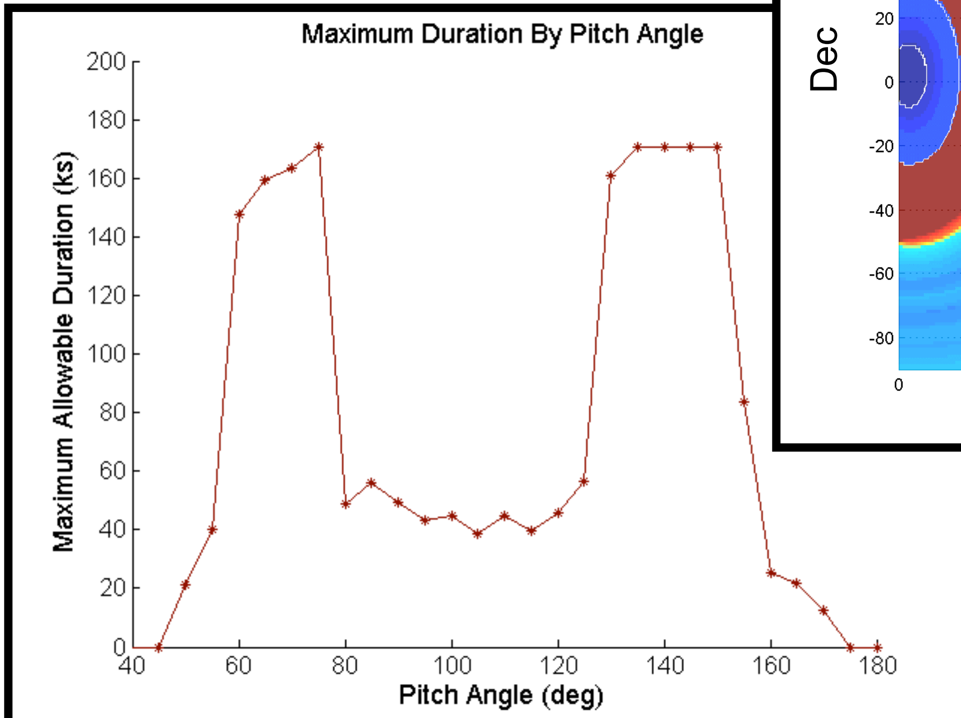
Scheduling Constraint Summary

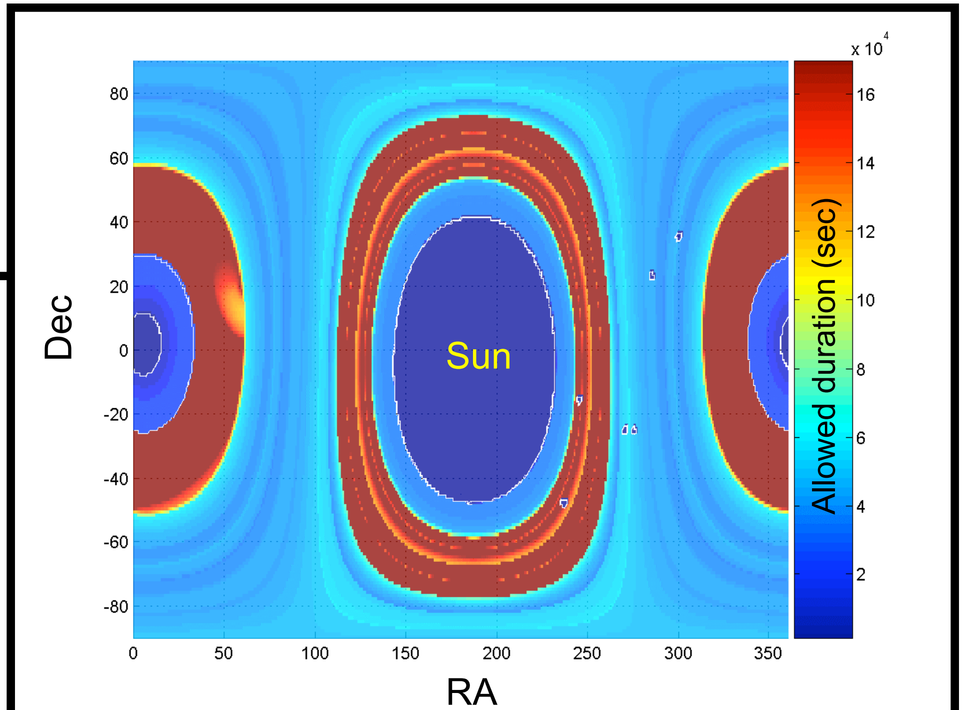
Science	Target, Window, Phase, Roll, Coordination, and Target of Opportunity turnaround time all dictate when an observation can be scheduled and how difficult it is to schedule. Any of the above can also be specified as a preference.
Attitude	Sun position constraints, planetary and bright X-Ray source avoidance, and star quality requirements all impact when an observation can be scheduled.
Thermal	EPHIN temperatures, Propulsion Line temperatures, thruster temperatures, ACIS Power Supply temperatures and (potentially) ACIS Focal Plane temperatures all impact if and when an observation can be scheduled
Consumables	Minimizing number of momentum unloads and SIM moves do not currently drive scheduling, but if ignored entirely may become increasingly important
Radiation	Radiation Zones determine the time in any given orbit that can be used for observations



Allowed Dwell Times Late September 2007

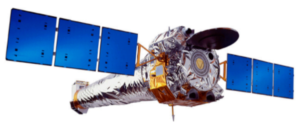
Using current constraints these plots show the maximum allowed dwell at every attitude





Assumes best case starting conditions at all attitudes

Durations capped by Radiation Zone limits



Translating Allowable Dwell Times to Observing Impact

Observing Efficiency

- **Observation durations and maneuver durations drive observing time efficiency**
- **Short allowed dwell times in large areas will force observations to be split, reducing efficiency**
- **Short allowed dwell times in smaller areas can be handled by placing targets well in the LTS and will generally have a small efficiency impact**
- **Short allowed dwell times near 90 deg-sun pitch will force splitting observations (some targets are always normal sun), reducing efficiency**
- **Pre-heating and pre-cooling requires large slews, reducing efficiency**

Target Availability

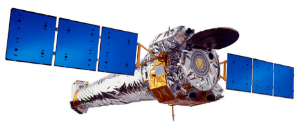
- **Short allowed dwell times impact the times of year long observations can be completed**
- **Short allowed dwell times near normal sun prevent completing some long observations without interruption**
- **Eliminating portions of the sky (away from normal sun) can prevent completing time constrained observations**
- **Eliminating portions of the sky near normal sun will prevent completing some observations all together**

Constraints with Potential to Change

- **Thermal**
  - Thermal constraints will change with time due to degradation of passive thermal controls
- **Science**
  - Degradation of SIs and increasing complexity of observing programs can significantly impact science related constraints
- **Radiation**
  - Radiation Zones will change with the shape of the orbit
- **Attitude**
  - Angular size of the earth changes with the orbit
  - Hardware failures may change attitude constraints
- **Momentum Handling (Attitude and Consumables)**
  - Magnitude of gravity gradient torques will change with the orbit
- **Use of Consumables**
  - Secondary effects of Thermal, Science and Momentum constraint changes

Spacecraft Constraint Trends

- **EPHIN**
  - EPHIN temperatures will continue to increase, which would make the limit increasingly restrictive
  - After study and risk analysis, a limit relaxation plan is in place
    - Limit will increase ~2º F every ~3 months
    - Increases will stop at 140º F or when degradation of EPHIN performance is detected
  - Planned limit increase will outpace impacts of increasing temperature
- **ACIS PSMC/DEA Power Supply**
  - Temperatures will continue to increase slowly
  - Observations with 6 chips currently limited in duration
  - Eventually 5 chip observations will also be limited
  - It is expected that observations with 4 or fewer chips will remain unlimited in duration for the 15 year mission
- **Thermal models have been developed for EPHIN and the ACIS PSMC**
  - Can use models to predict impact of trends on constraints

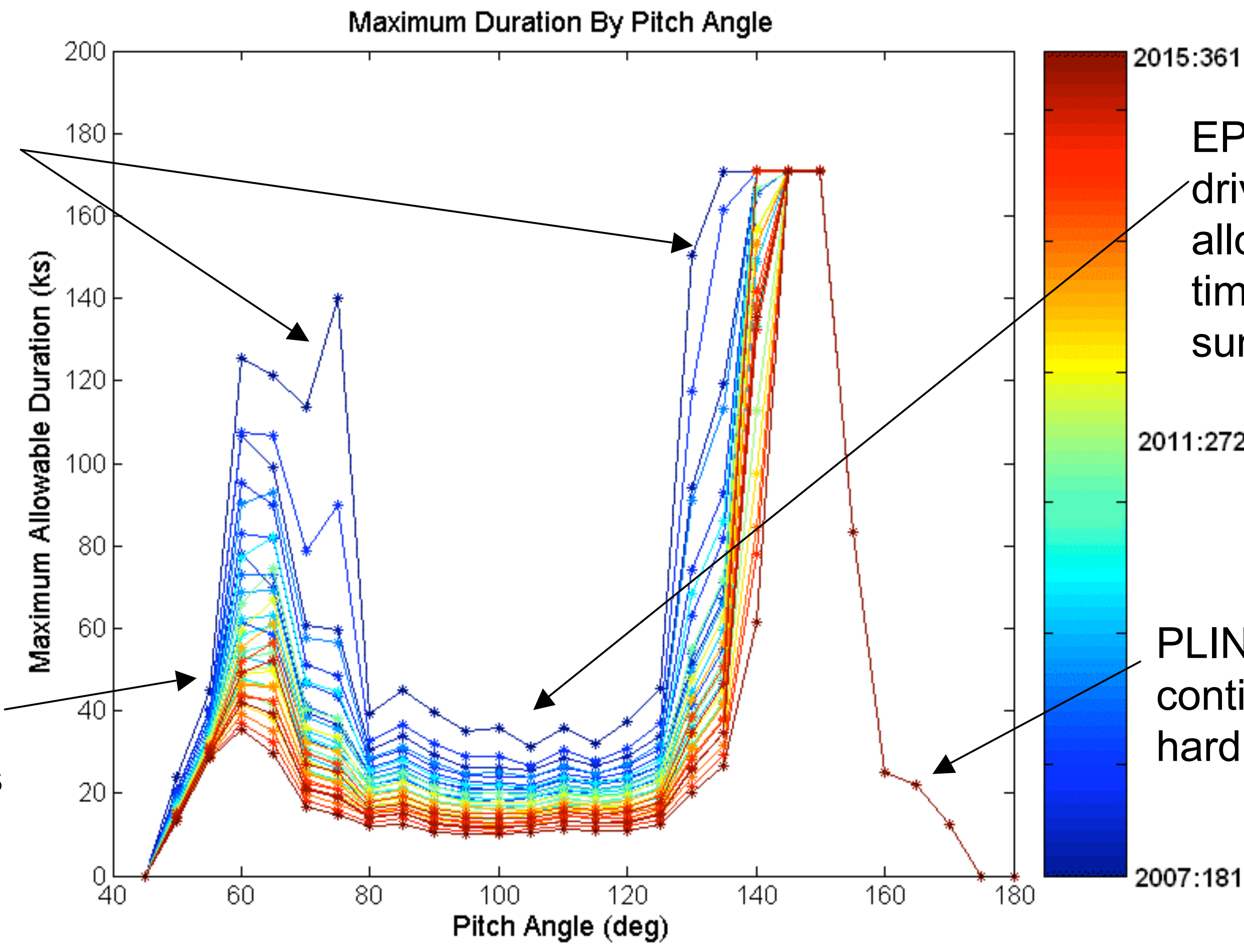


Maximum Allowable Dwell Time Predictions

These curves are predictions using current trends and constraints

Restricted pitch region grows

Regions limited by EPHIN and ACIS PSMC/DEA temperatures intersect



EPHIN constraint drives down allowable dwell times at normal sun

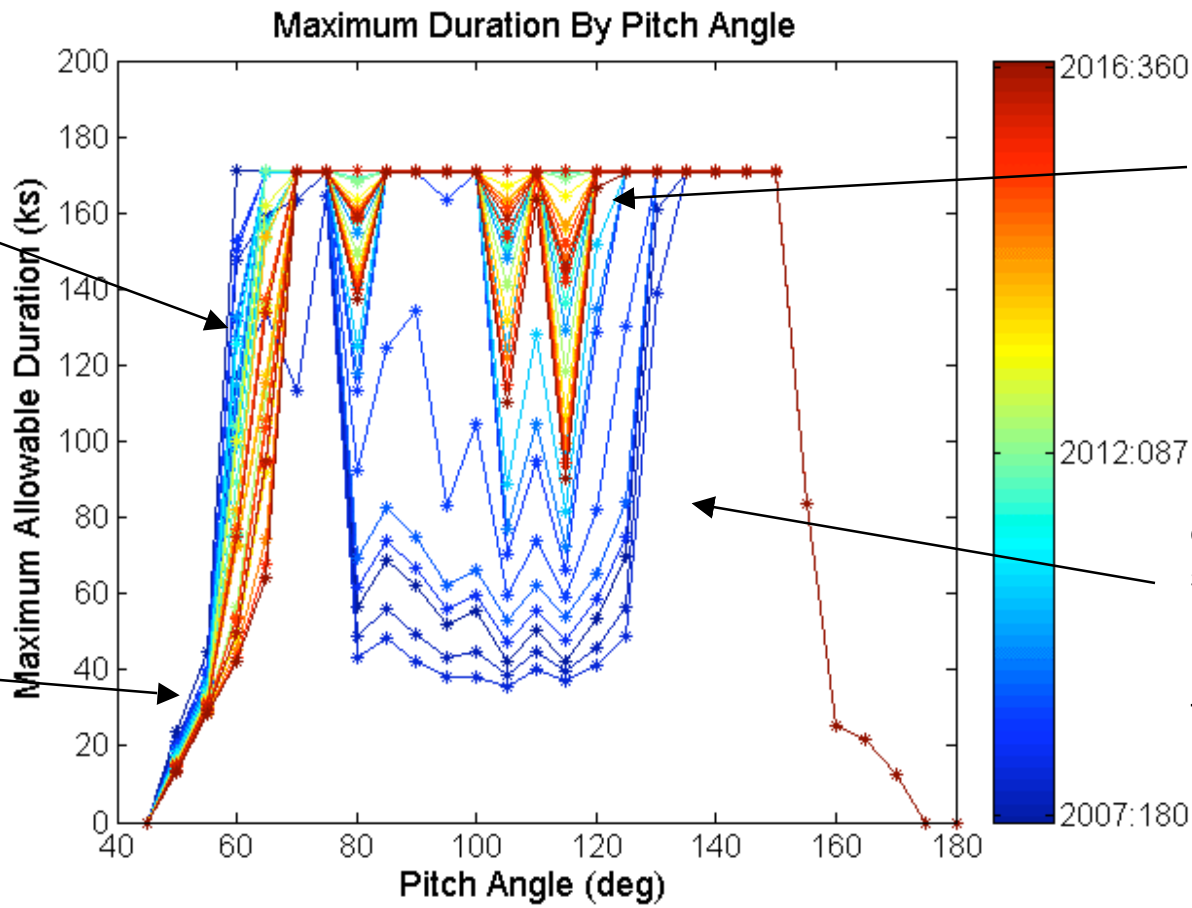
PLINE constraint continues to limit hard tail-sun time

Predicted Maximum Dwell Times
6 Chip Observations

These curves are predictions using current trends, plans and constraints

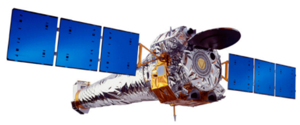
Time forward of 65 decreasing due to ACIS PSMC constraint

Time forward of 55 severely restricted by ACIS PSMC



There will continue to be duration limits during the hot season with a EPHIN limit of 140

EPHIN relaxation opens up normal sun – by 2009 normal sun unconstrained at times of year



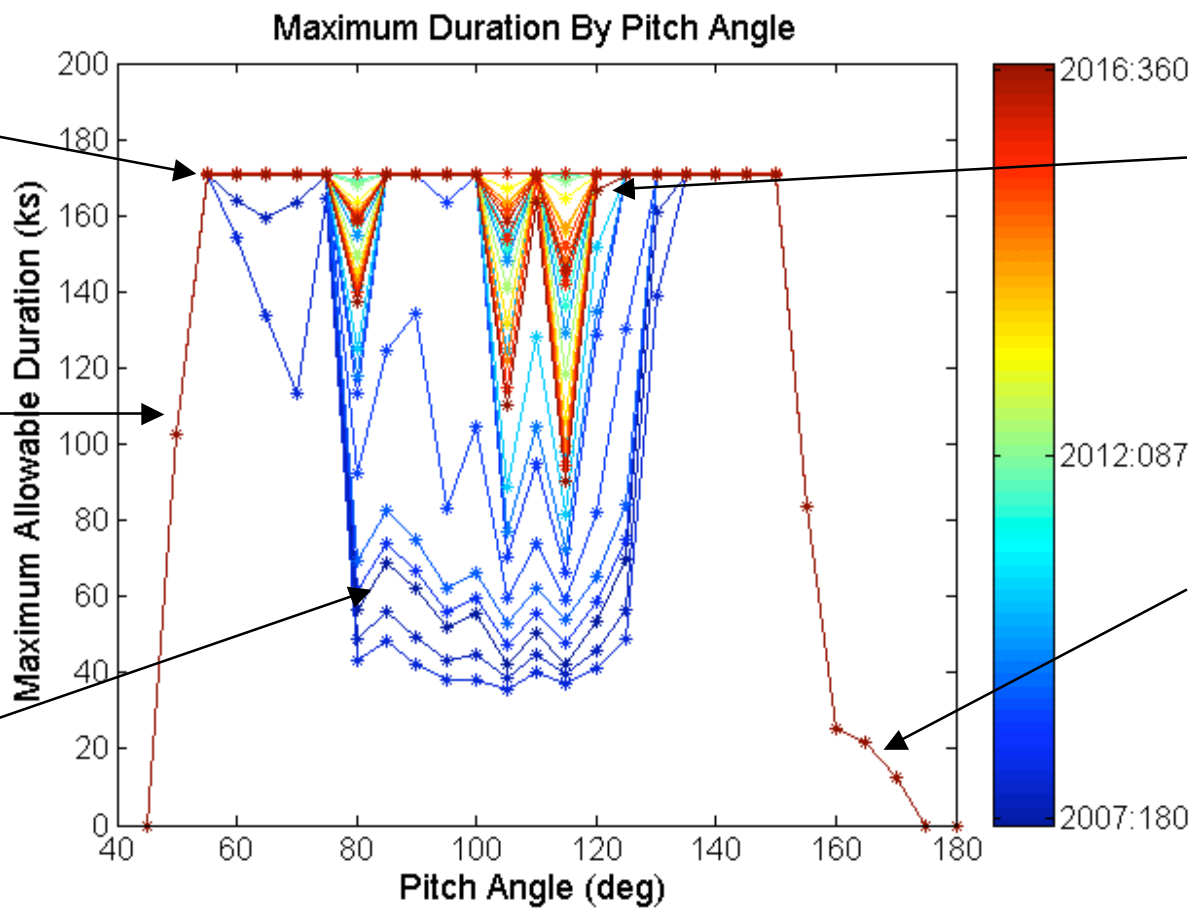
Predicted Maximum Dwell Times
4 Chip Observations

These curves are predictions using current trends, plans and constraints

No duration constraint at 55

Long dwells forward of 50 allowed – Off-Nominal roll becomes the limiting factor

EPHIN relaxation opens up normal sun



There will continue to be duration limits during the hot season with a EPHIN limit of 140

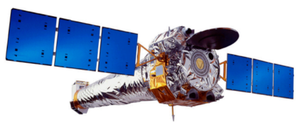
PLINE continues to limit tail sun time

Additional Constraint Changes

- **PLINE**
  - Addition of on-board monitor has reduced consequence of overestimating time to cold temperatures
  - Temperatures at the front (152) edge of the region may now be warm enough for unlimited dwells
  - Pre-heating requirements may become easier to achieve as the vehicle warms
- **ACIS Focal Plane (FP)**
  - ACIS FP warmer than -119.7º C at attitudes tail-sun of 120 deg sun-pitch
  - Earth impinging on the radiator Field of View also increases temperature
  - Investigation into impacts and mitigation options underway
  - Attitude restrictions have been presented as a mitigation option
    - Not clear what maximum dwell times would become
    - May apply only to some observations
    - Investigating other options first
- **Fine Sun Sensors**
  - Fast time constant makes scheduling constraints to protect the FSS somewhat impractical
  - If forced to operate without a FSS, the sun constraints may need to be tightened

Summary of Constraint Changes

- EPHIN constraint relaxation will slowly open up normal sun attitudes
- ACIS PSMC/DEA constraint will grow slowly more restrictive at far forward sun
  - Observations with 4 or fewer chips not expected to become time limited
- PLINE trends may allow small relaxation of tail-sun constraints
- ACIS FP temperatures may limit tail-sun durations for some types of observations
- FSS Trends may require modification of sun constraint



Summary

- The vehicle hardware is in good health and should support a 15 year mission
- The degradation of the sun side surfaces will continue
  - Degradation is slowing
  - Most elevated temperatures can be managed with constraints
  - Small potential performance impacts
- The orbit will support a 15 year mission
  - Primary challenges will be momentum management and re-characterizing the radiation environment
- Constraints will continue to evolve
  - EPHIN relaxation plan will allow longer observations
  - Changes will be announced as soon as possible