ACIS HW Training

I. HW Overview

II. Flight Operations Concerns

III. Flight Anomalies and Response

IV. Bakeout from a HW perspective

Things You Must Know at the End of this Briefing

1. The ACIS Door was opened once and we have no plans to close the door again in the mission, but it is possible to close or partially close the door.
2. The ACIS DH has been heated from -60 C to +25 C twice in the mission.
3. The 10 video boards in the DEA are connected to a specific CCD. If we lose a video board, we have lost that CCD. There is NO multiplexing in the DEA.
4. The 6 FEPs in the DPA are multiplexed to all 10 CCDs. We can lose a single FEP and we would still be able to clock any CCD.
5. Side A and Side B of the DPA must be powered on to clock 6 CCDs. FEPs 0, 1, 2 are powered from side A and FEPs 3, 4, 5 are powererd from side B. If we lose a side of the DPA, we lose 3 CCDs.

Overview of ACIS HW

ACIS HW, MAIN COMPONENTS:

DEA, Detector Electronics Assembly - analog electronics to clock the CCDs and process analog data, contains video boards for the CCDs [MIT]

DPA, Digital Processing Assembly - contains Back-End Processors (BEPs) and Front-End Processors (FEPs), processes digital data from the from DEA (CCDs) and SW commands [MIT]

DH, Detector Housing - contains CCD focal plane (FP), optical blocking filter (OBF), proton shield, collimator [Lockheed-Martin and Lincoln Laboratories]

PSMC, Power Supply and Mechanism Controller - power supplies, door and valve controllers, connection to the ISIM RCTU, processes HW commands [Lockheed-Martin]

Radiators - Warm (connected to DH) and Cold (connected to FP) radiators [Lockheed-Martin]

ACIS Flight SW:

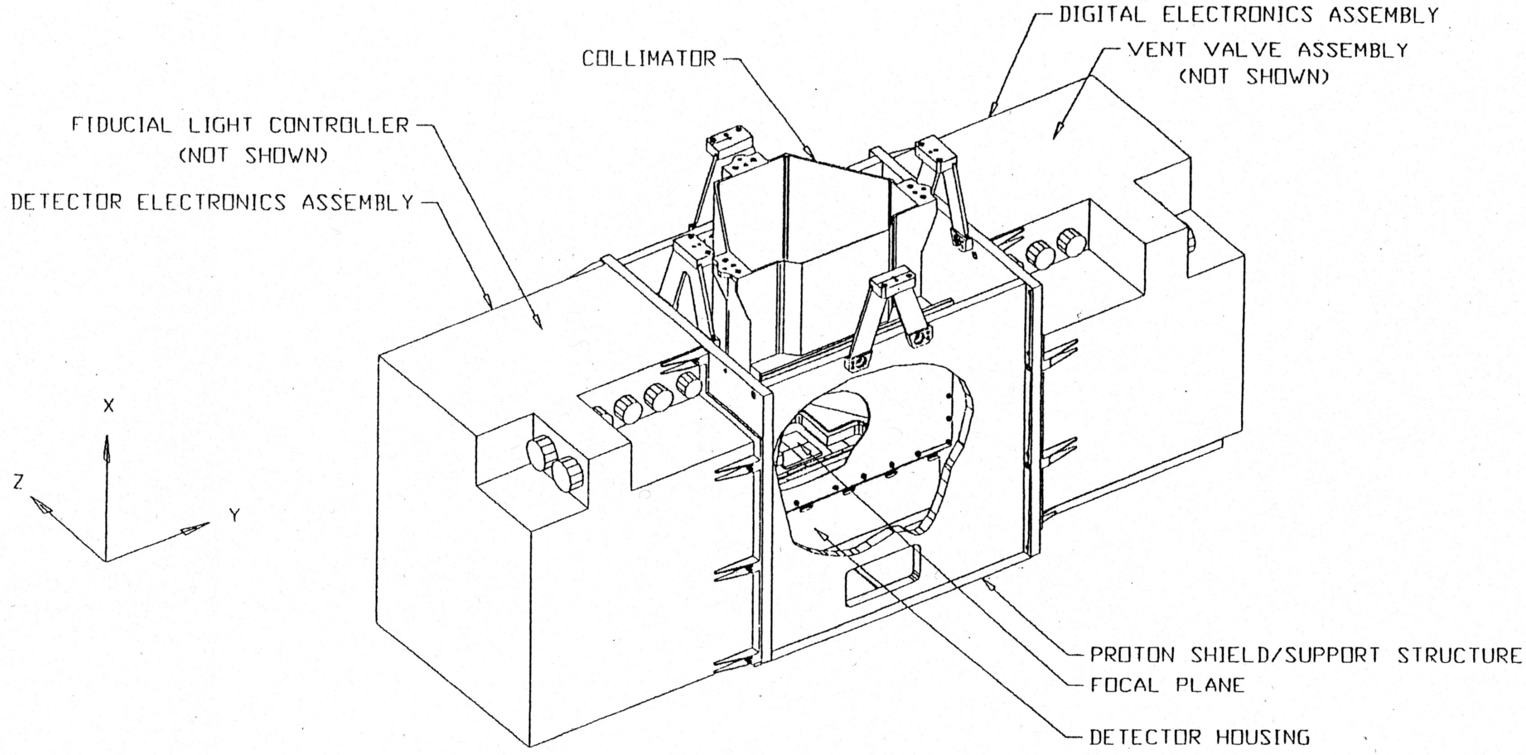
- ACIS BEPs controls all science functions: which CCDs are on, which video boards are on, which FEP is connected to which CCD, ACIS TLM formats, etc.
- "Normal" commanding entails only ACIS SW commands, we rarely send HW commands. The last HW commands were to turn off and disable the DH heater. This means the weekly *Chandra* load usually contains only SW commands.
- ACIS SW commands are of variable length, the parameter block is the most important, it contains about 150 commands
- Flight SW has been patched several times since launch, the latest version is loaded by SOP_ACIS_SW_STDFOPTG (8/8/2016)

References:

- DPA Hardware Specification- http://acis.mit.edu/axaf/dpa/
- DPA/DEA Interface Control Document - http://acis.mit.edu/axaf/deadpaicd
- ACIS Flight SW Users Guide - http://acis.mit.edu/acis/swuserA/
- ACIS Operations Handbook - http://acis.mit.edu/acis/sop01.v265/
- ACIS Flight SW Requirements Specification - http://acis.mit.edu/acis/sreqj/
- ACIS Flight SW Detailed Design Specification - http://acis.mit.edu/acis/sdetail/
- FEP0 Anomaly Report - http://acis.mit.edu/asc/fep0Rept.pdf
- Threshold Crossing Plane Latchup Report - http://acis.mit.edu/asc/tplaneanom1.html
- Hi/Lo Pixel Anomaly Report ftp://acis.mit.edu/pub/hi-lo-pixel-anomaly-v1.4.pdf
- ACIS Ops Flight Notes and Anomalies http://cxc.cfa.harvard.edu/acis/memos/webpage/memos_frames2.html

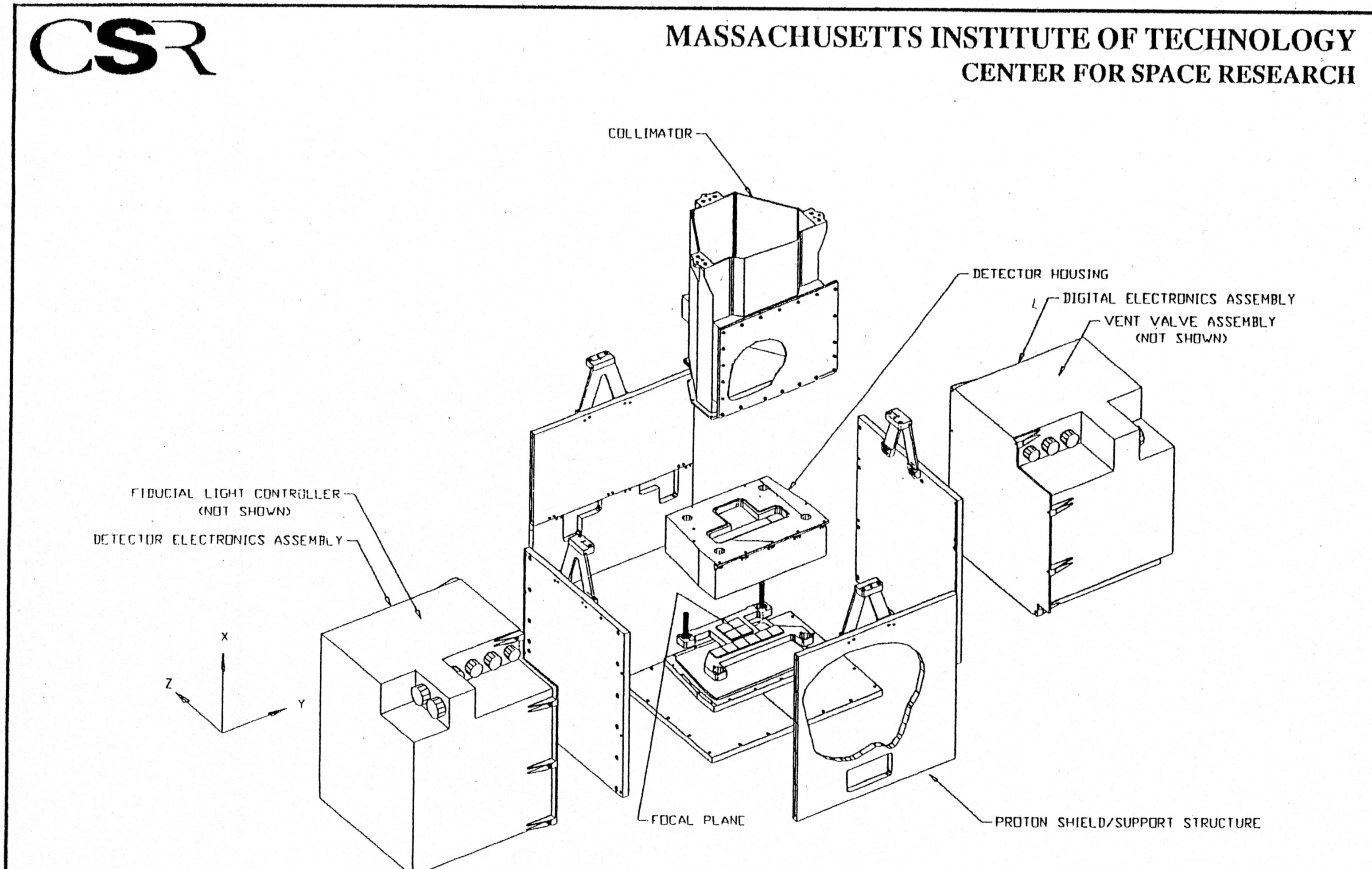
ACIS HW Diagram

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CENTER FOR SPACE RESEARCH



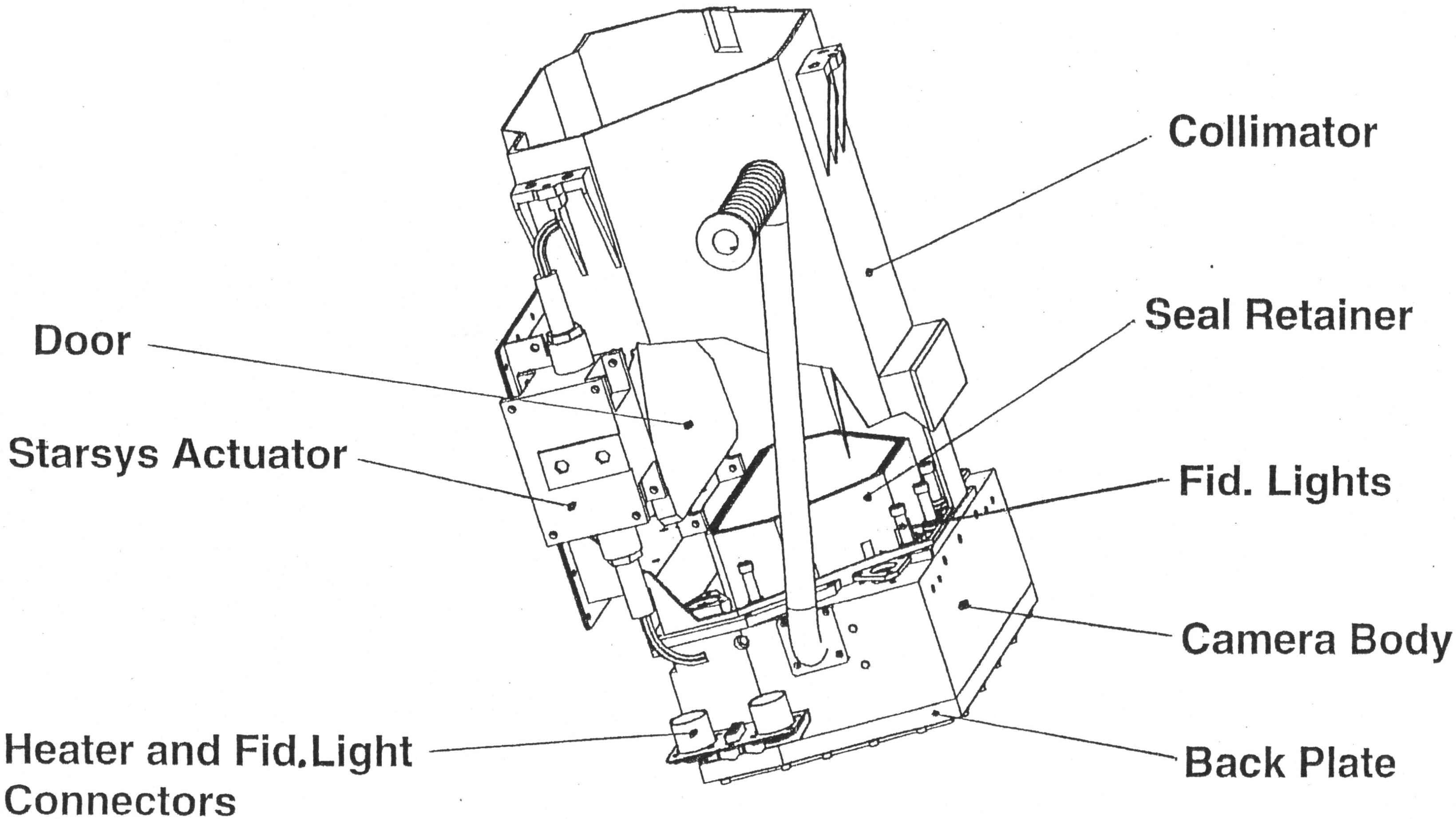
ACIS CAMERA CONCEPT DRAWING
FIGURE 1

ACIS HW Diagram Exploded View



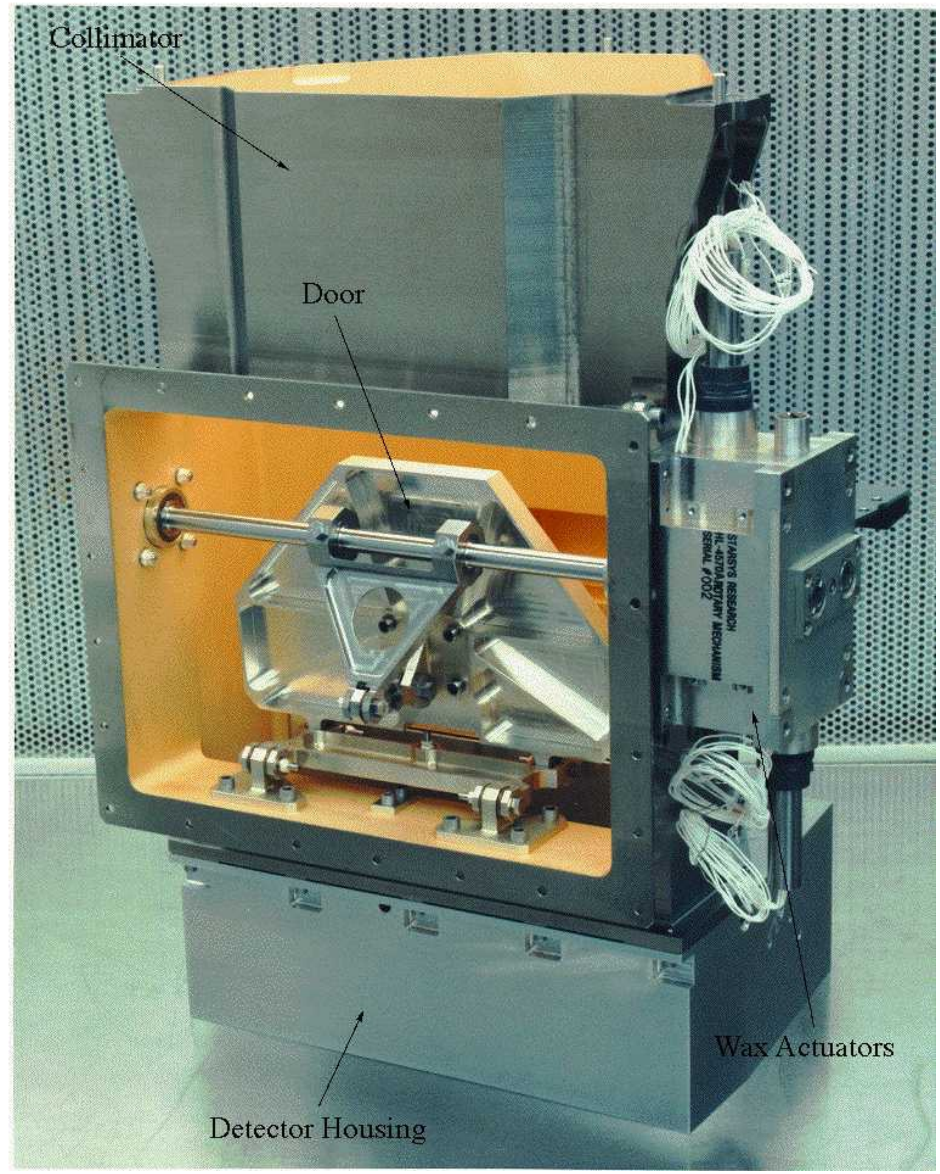
ACIS CAMERA CONCEPT DRAWING
FIGURE 1

ACIS Detector Housing

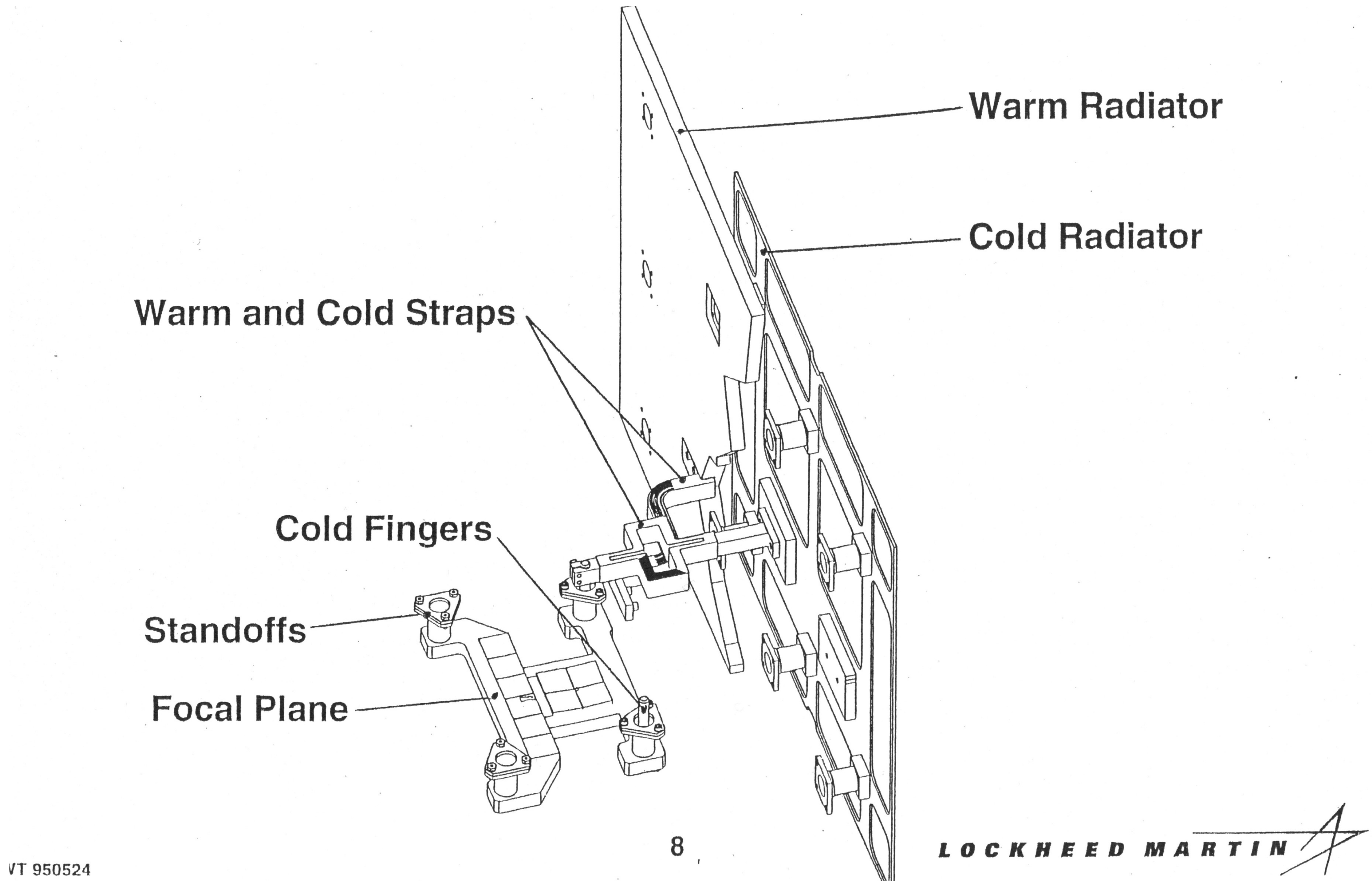


ACIS Engineering Unit & Door Mechanism

Door opened on 8 August 1999
Camera Body heated to
1CBAT/1CBBT to +17.8/22.8
FP heated to +31.6 C

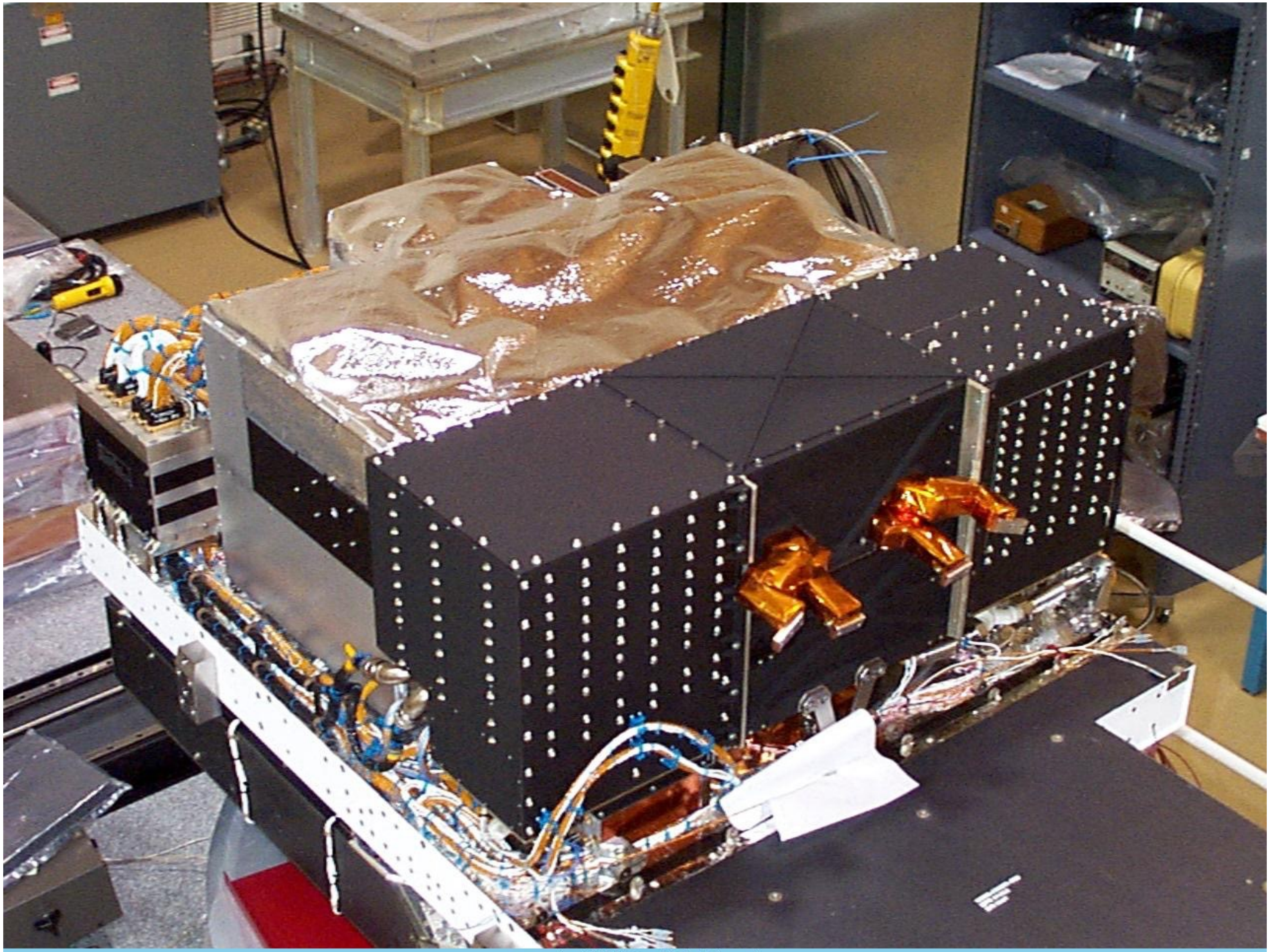


ACIS Focal Plane Support Drawings



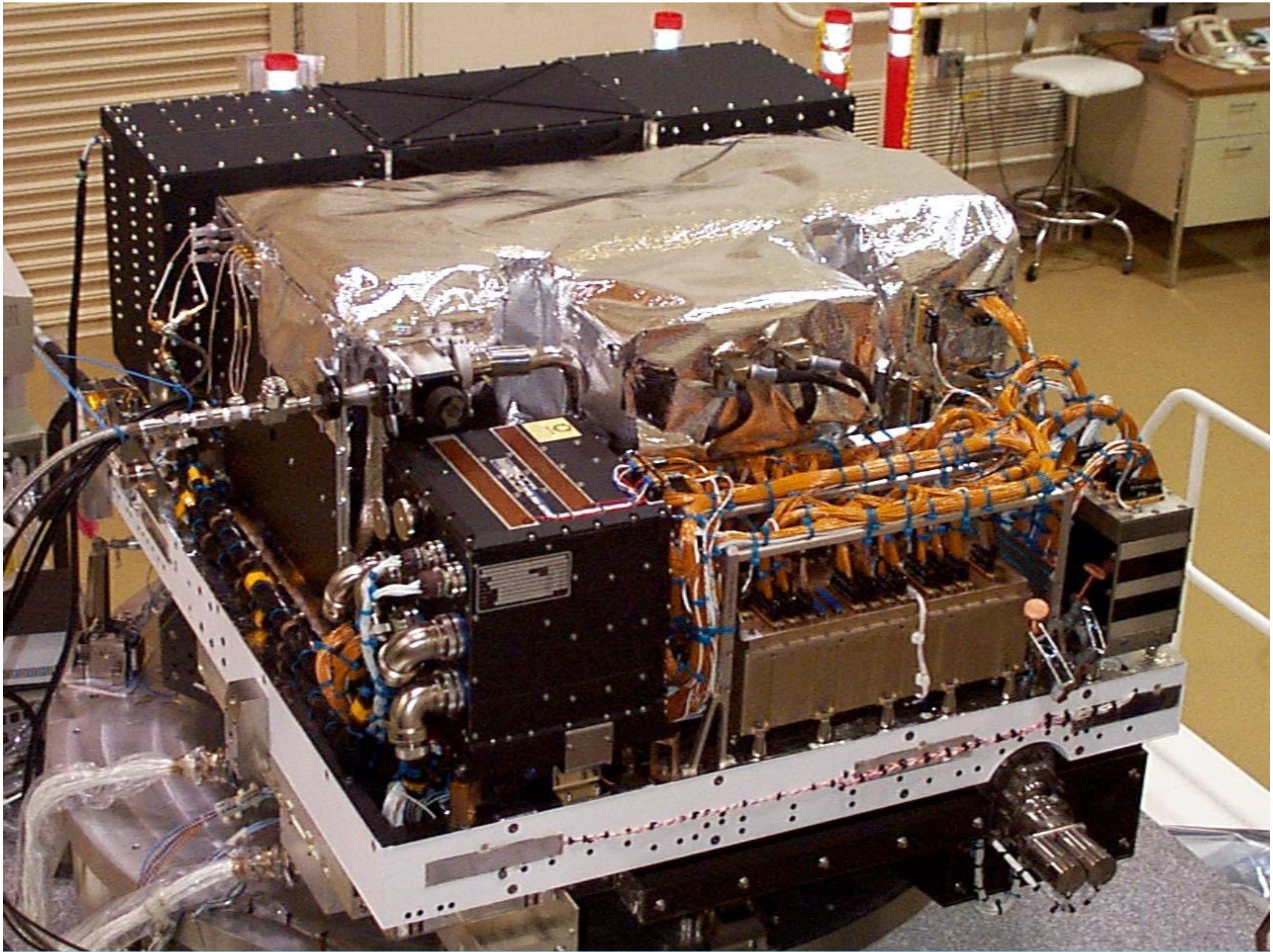
ISIM at Ball with SIs

ISIM at Ball with SIs



p000339.jpg AXAF/HRC at BASD J Chappell

ISIM at Ball with SIs

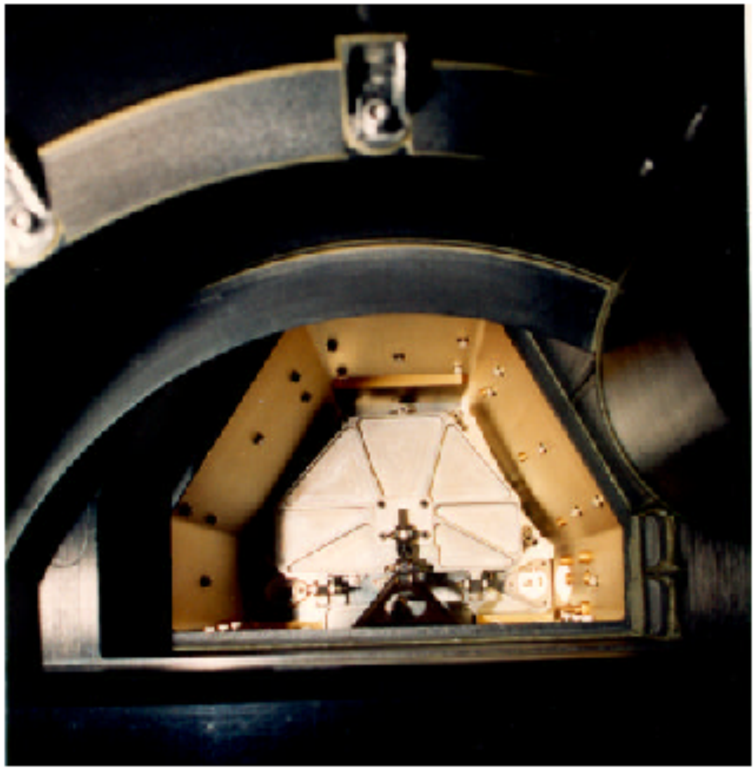


p000342.jpg AXAF/HRC at BASD J Chappell

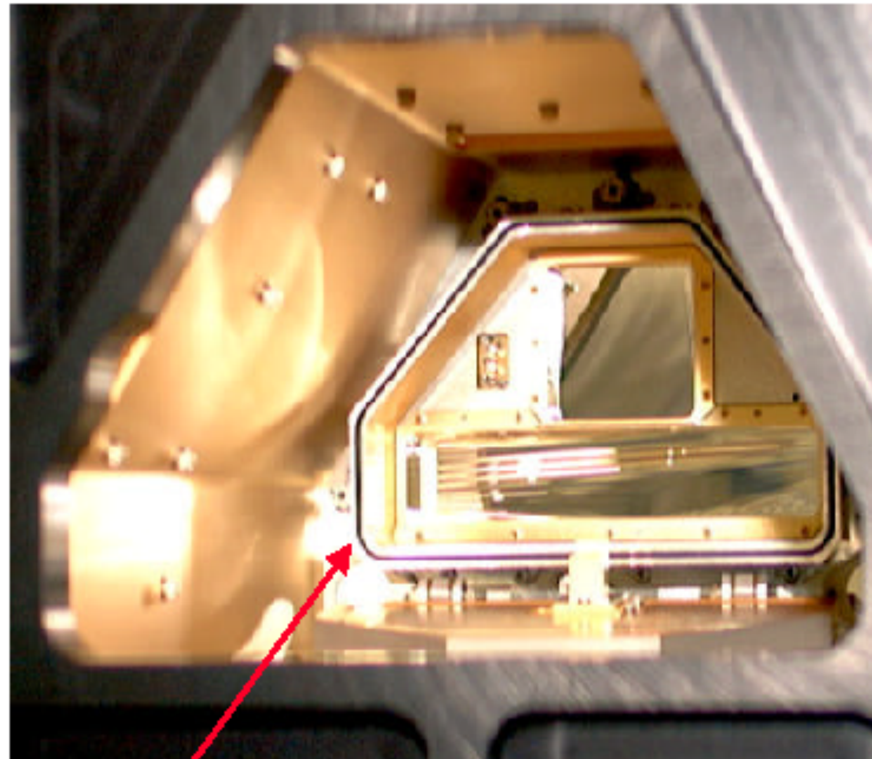
ISIM Assembled

p000385.jpg AXAF/HRC at BASD J Chappell

X-Ray View of ACIS Door and Detector



Door Closed while Mounted to ISIM



Door Open at LMA

Viton O-ring

1

LOCKHEED MARTIN

ISIM Interface

p000459.jpg AXAF/HRC at BASD J Chappell

ISIM on Chandra in Shuttle

dsc00013.jpg AXAF/HRC at KSC J Chappell

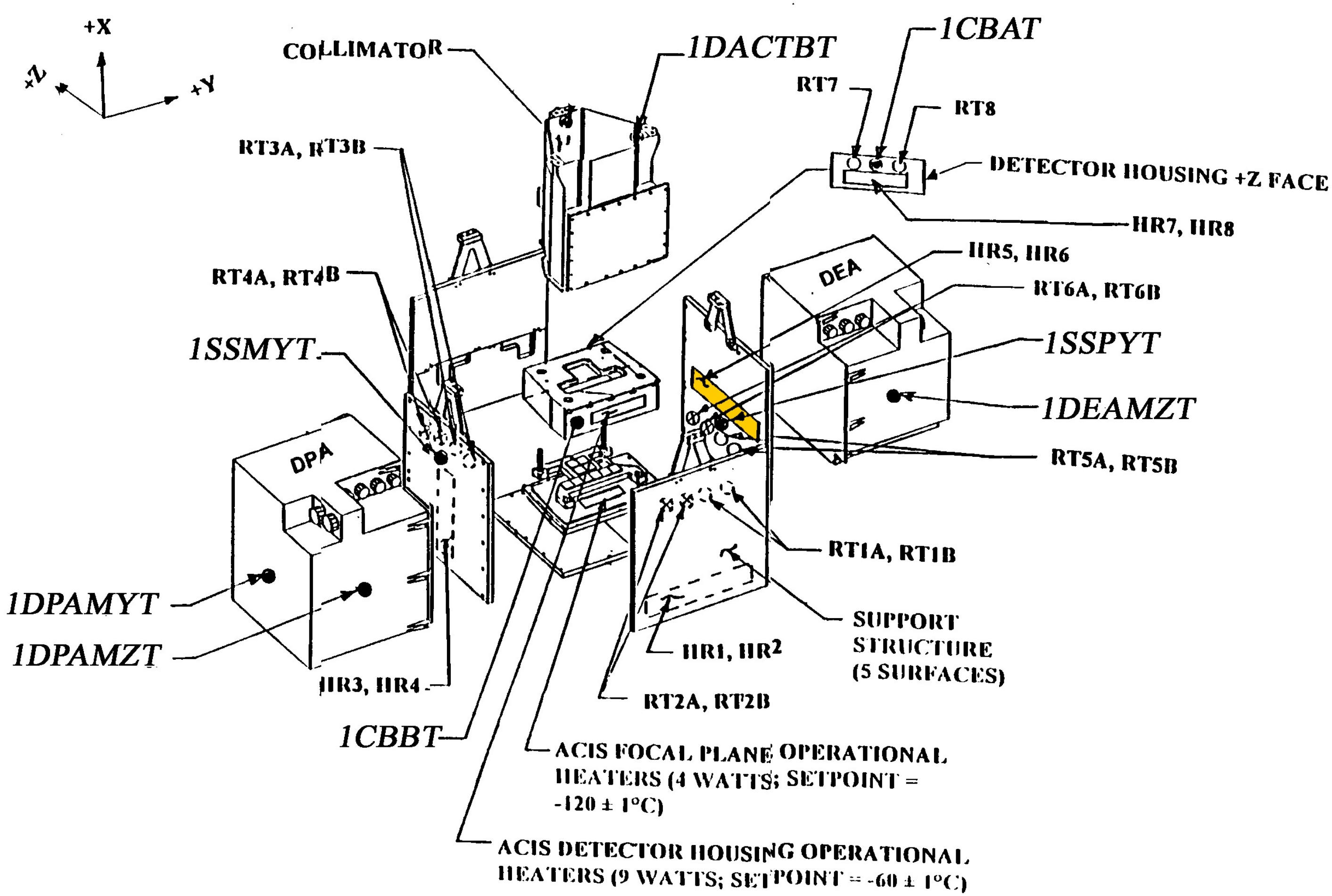
ISIM on Chandra in Shuttle

dsc00015.jpg AXAF/HRC at KSC J Chappell

ACIS SS & DETECTOR HOUSING TRIM & SURVIVAL HEATERS & TEMP. TELEMETRY

CHANDRA

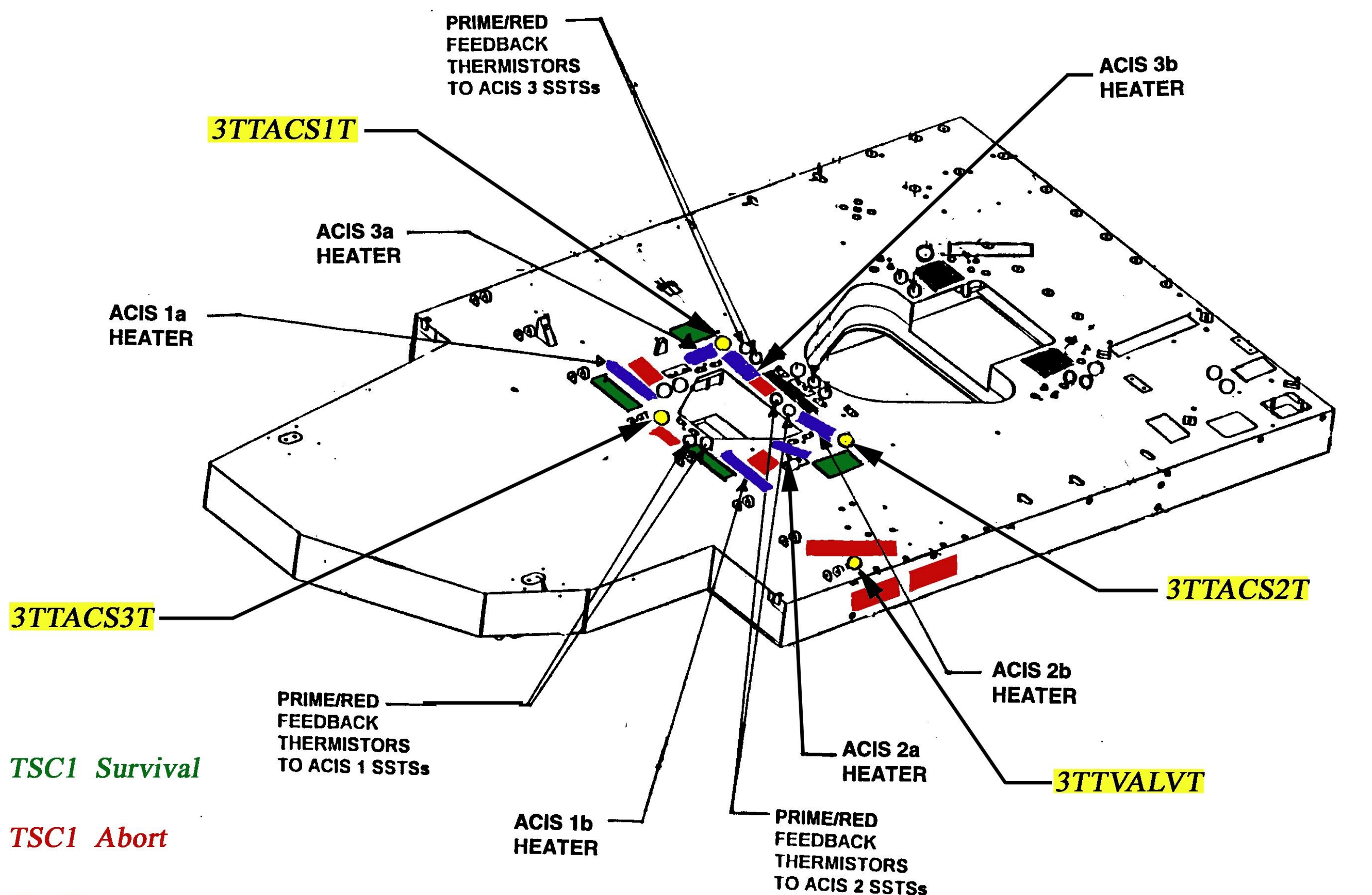
ACIS thermistors and heaters



CHANDRA

ACIS HEATERS ON TRANSLATION TABLE (-X SIDE)

ACIS thermistors and heaters on ISIM



TSC1 Survival

TSC1 Abort

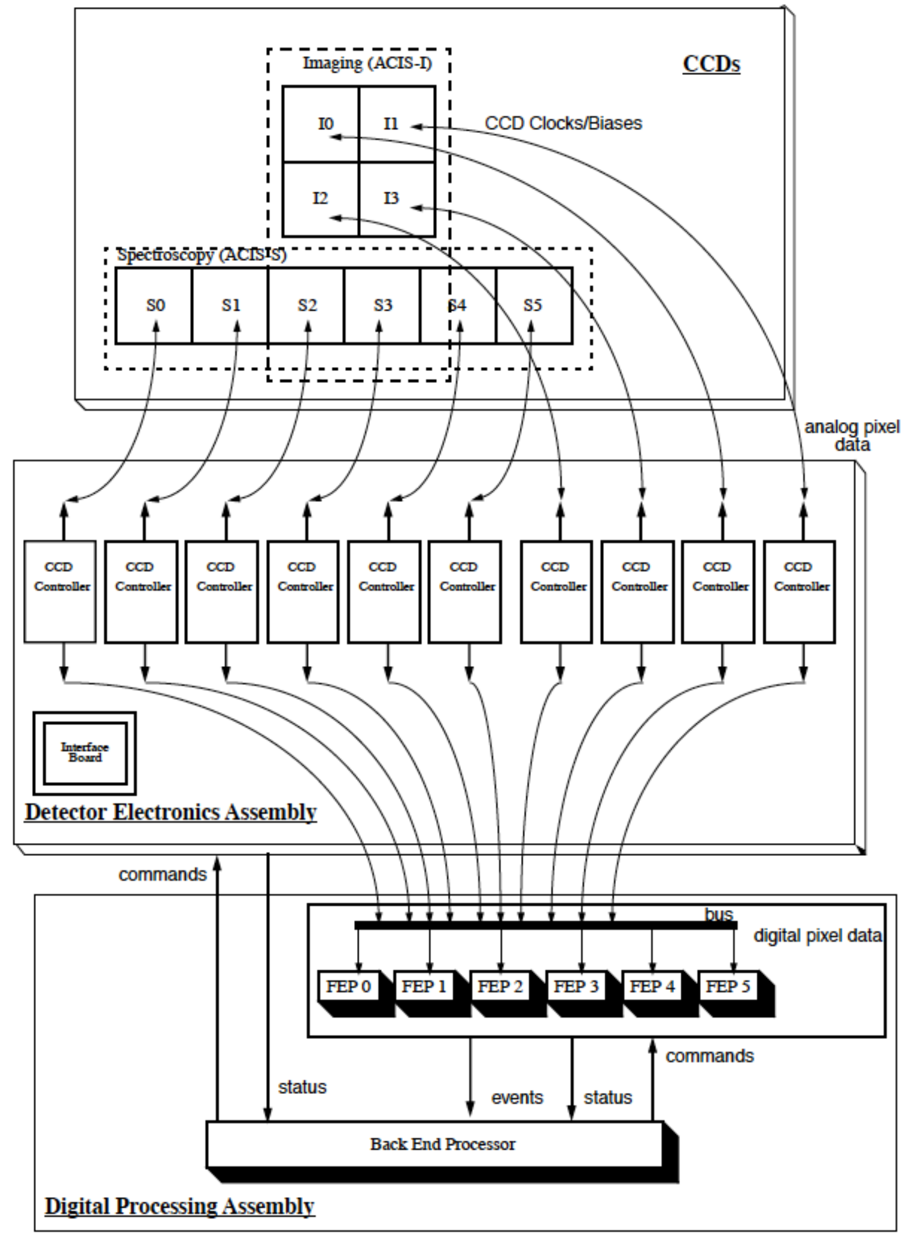
Gradient

ACIS CCDs, FEPs, & VB Connections

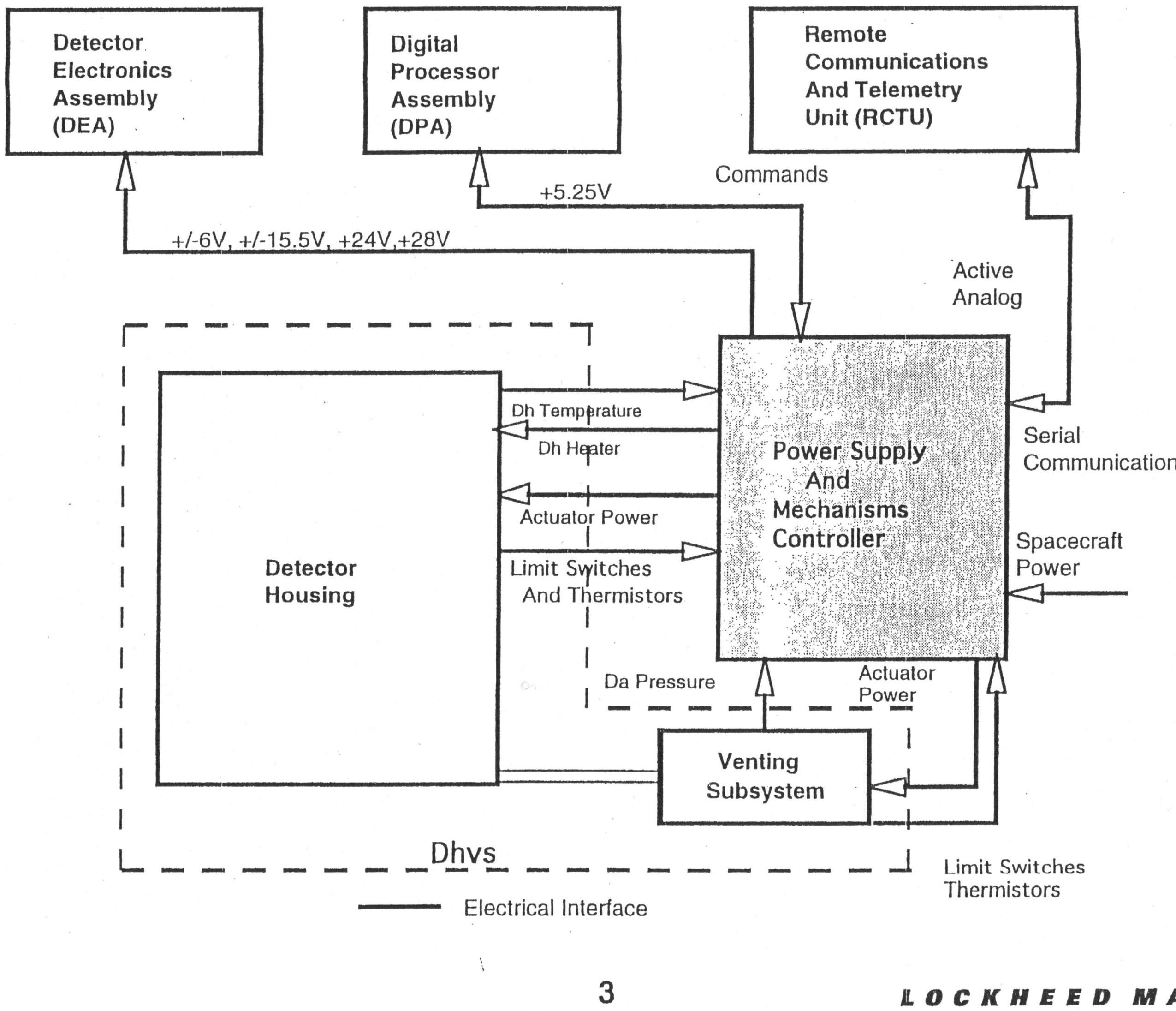
Video boards connected to one and only one CCD

FEPs are fully multiplexed, can be connected to any CCD

FIGURE 7. DEA Interface Overview



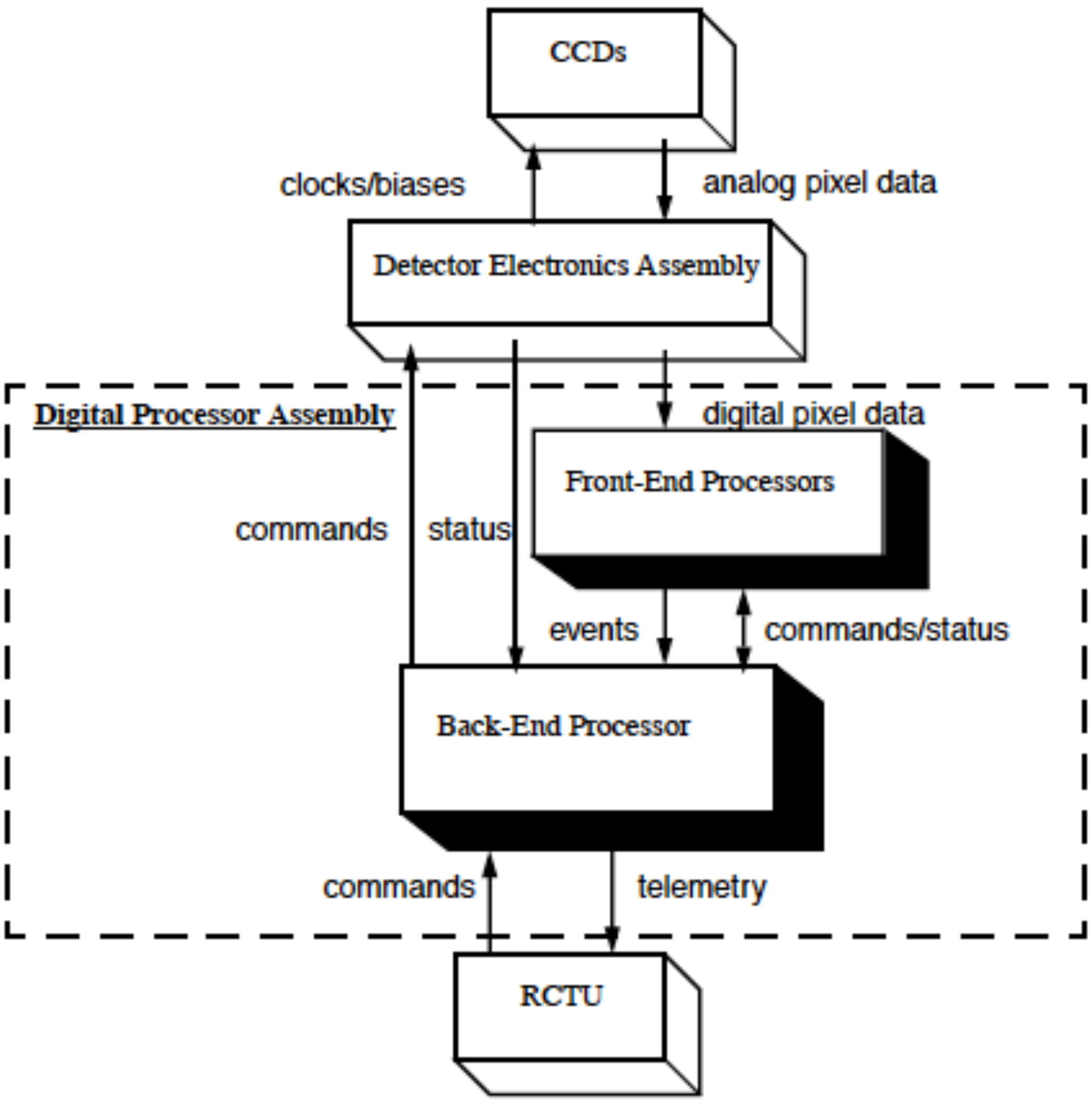
ACIS PSMC Interfaces



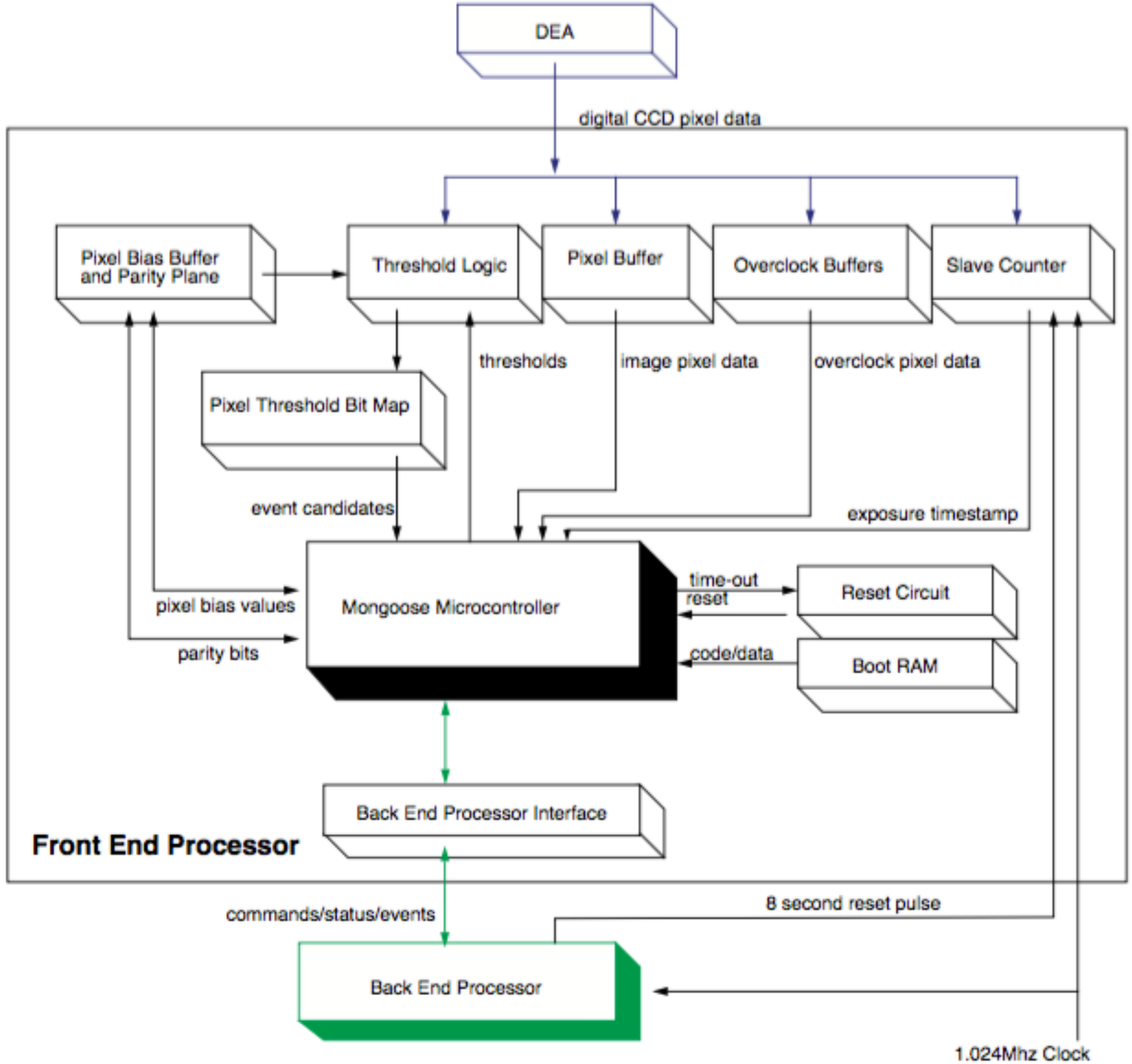
PSMC is the connection to the spacecraft, both in terms of power and HW commands/ telemetry

ACIS DPA Interfaces

FIGURE 1. DPA Interface Overview



ACIS FEP Architecture



FEP Memory Map

FIGURE 2-2. Mongoose Memory Organization

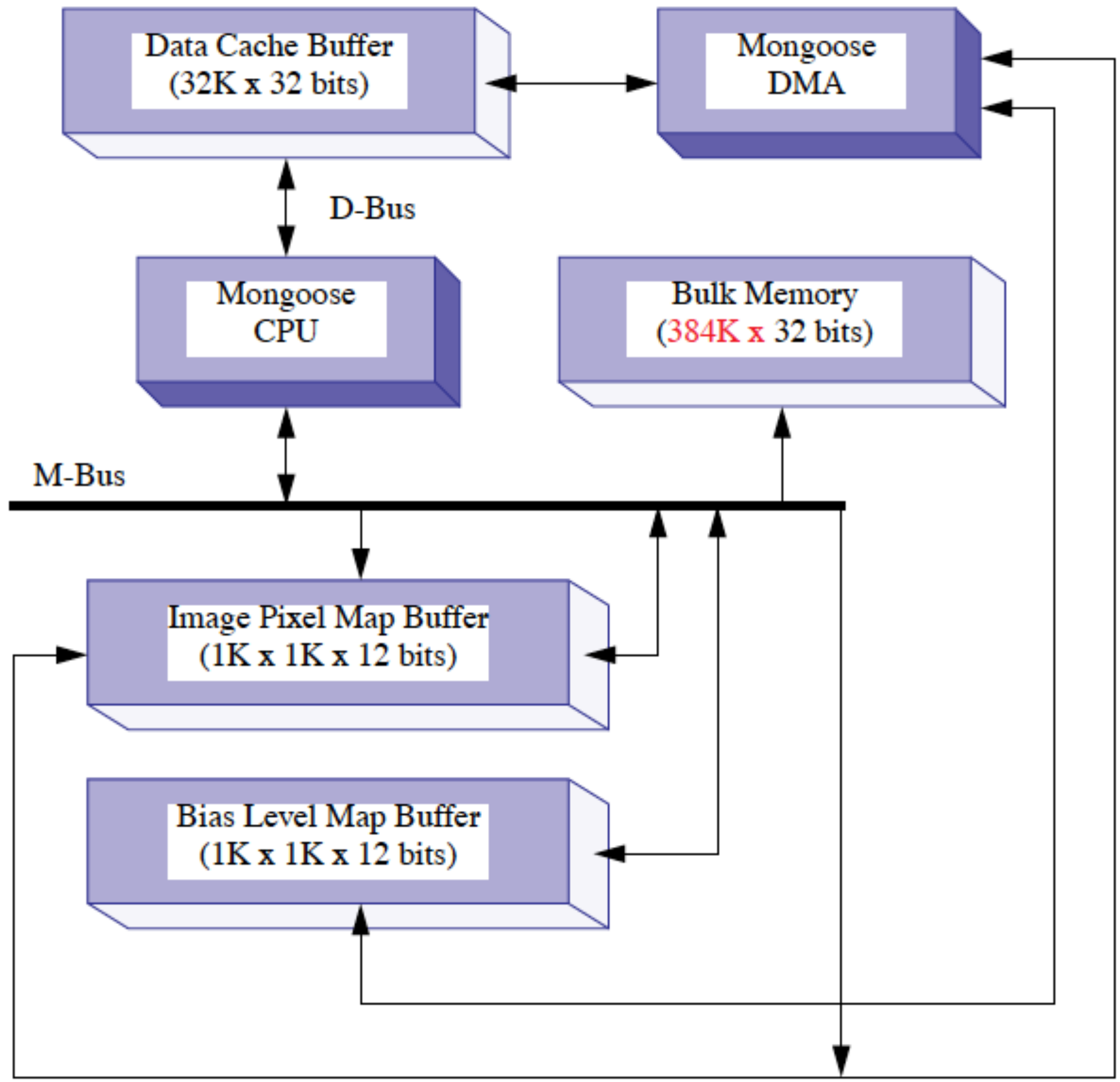
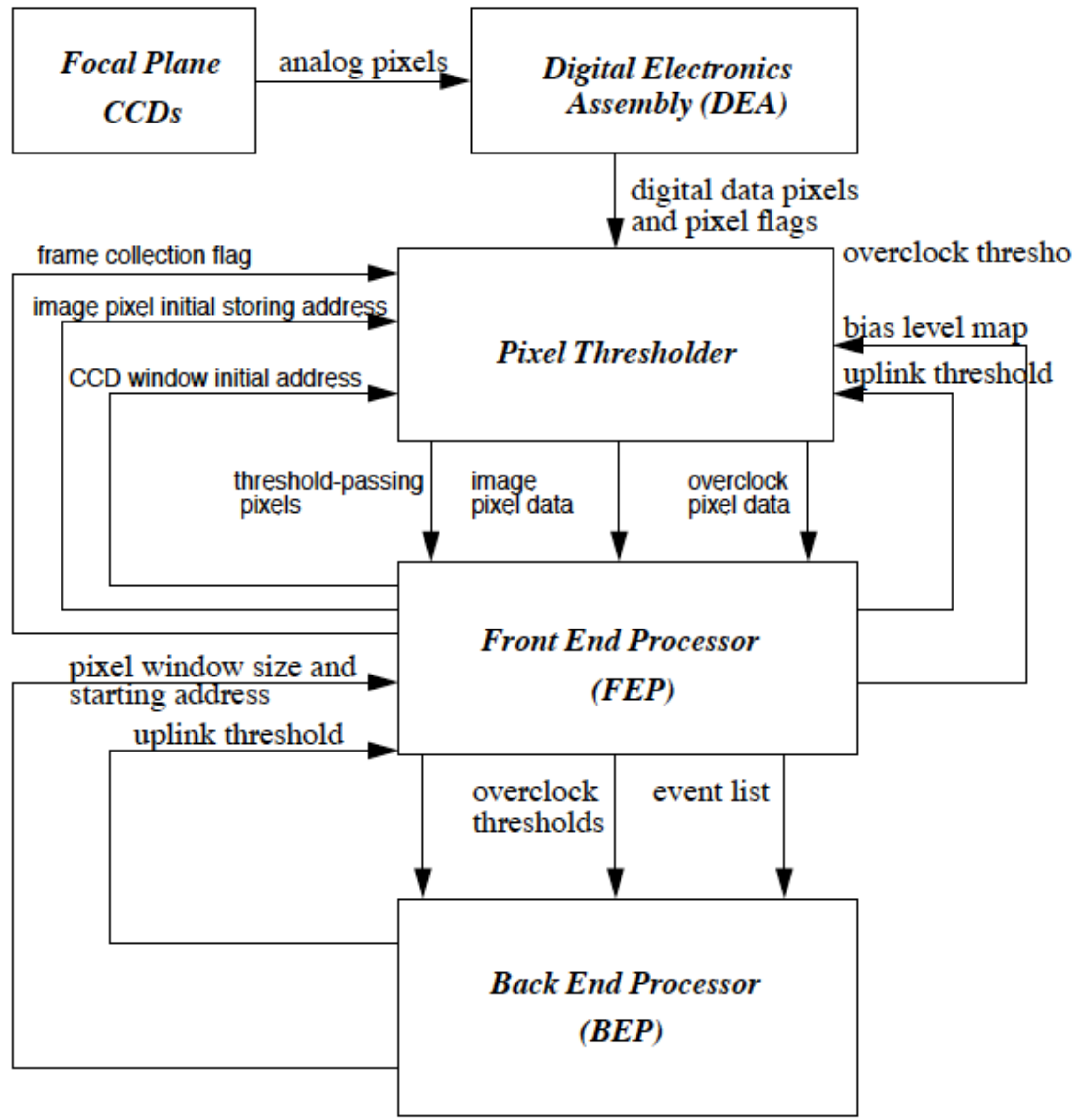


FIGURE 2-1. ACIS Data Flow involving Bias Levels

ACIS Data Flow



ACIS FEP Data Flow

FIGURE 2-3. Front End Processor Data Flow

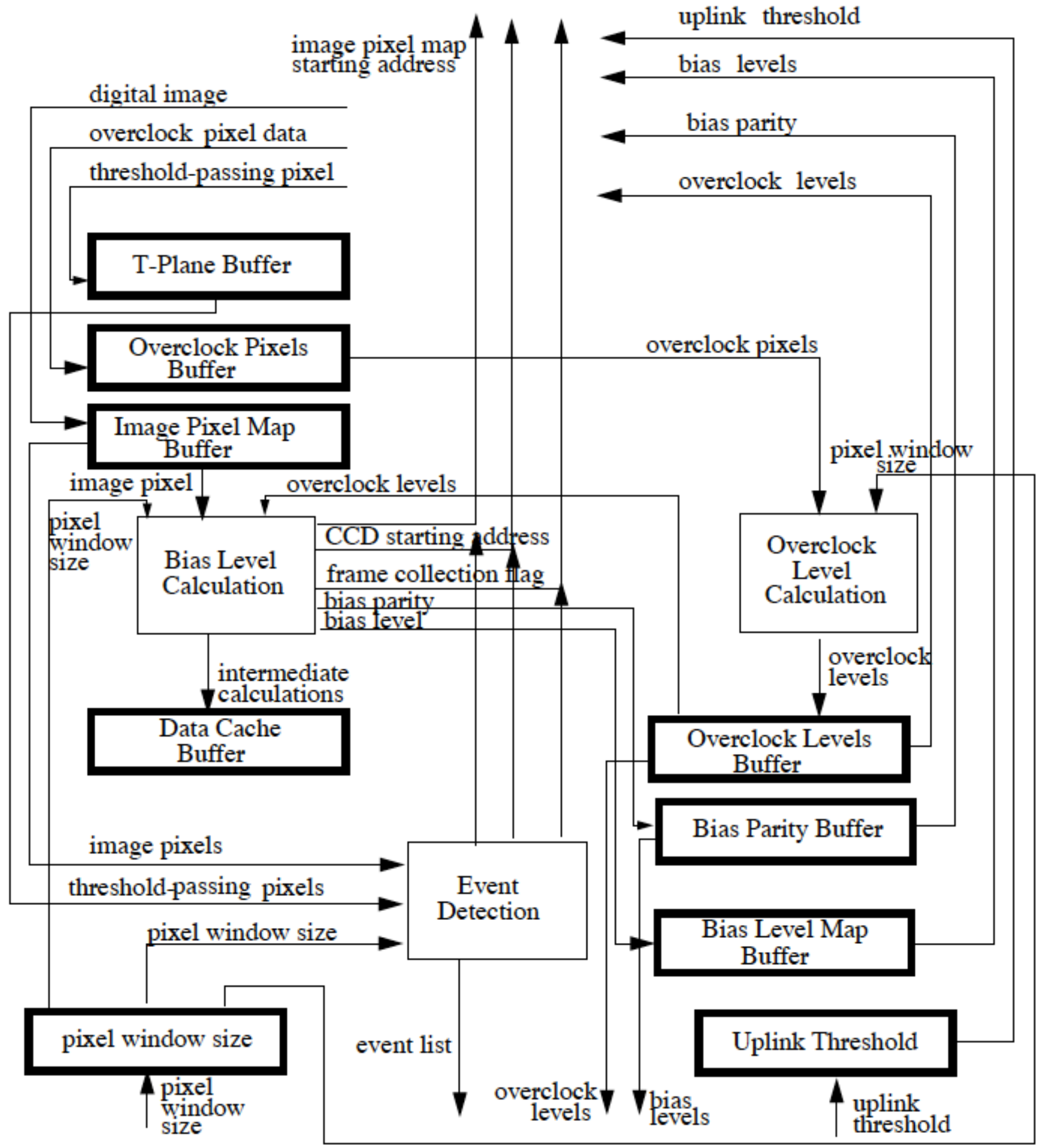
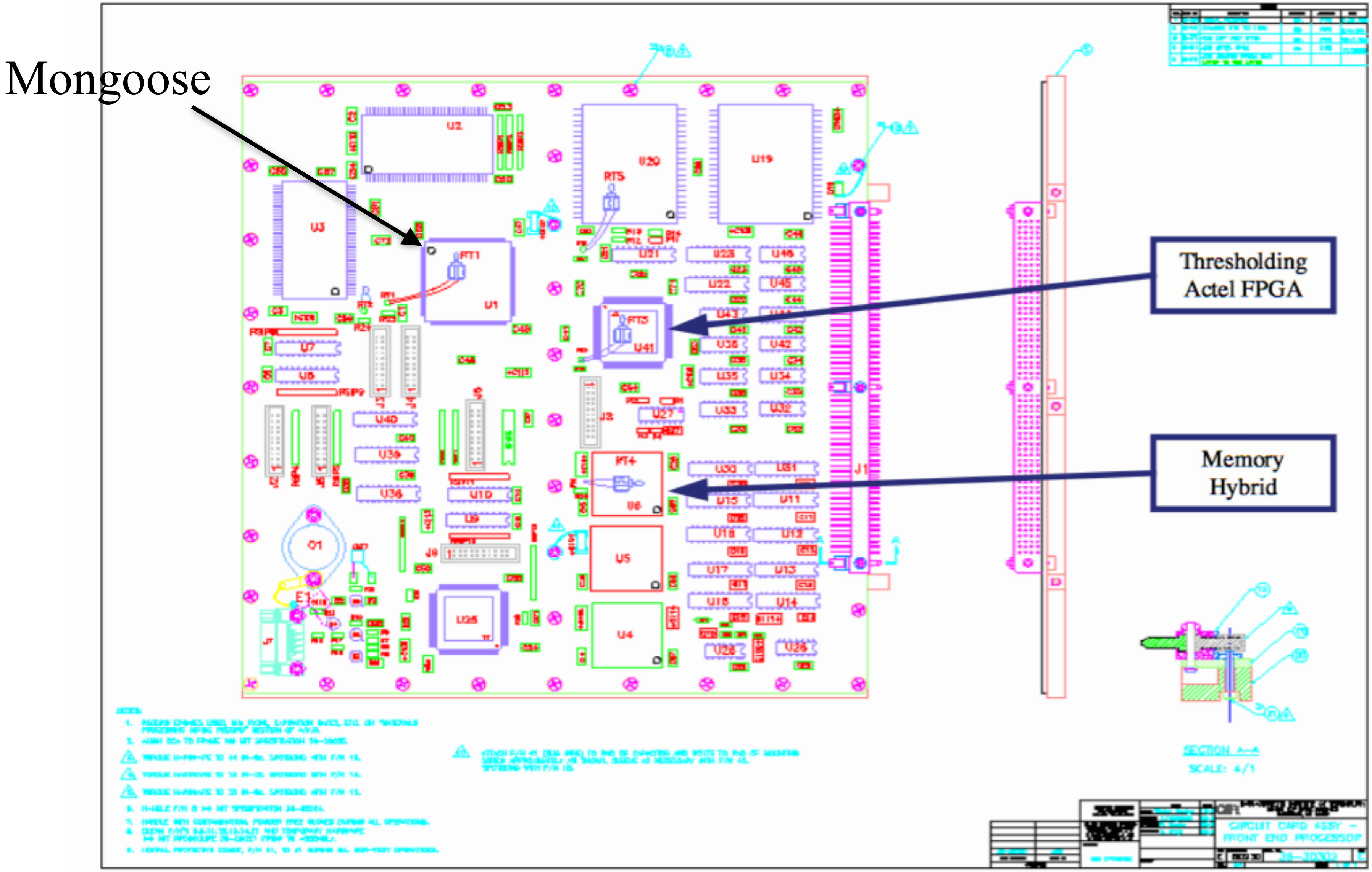
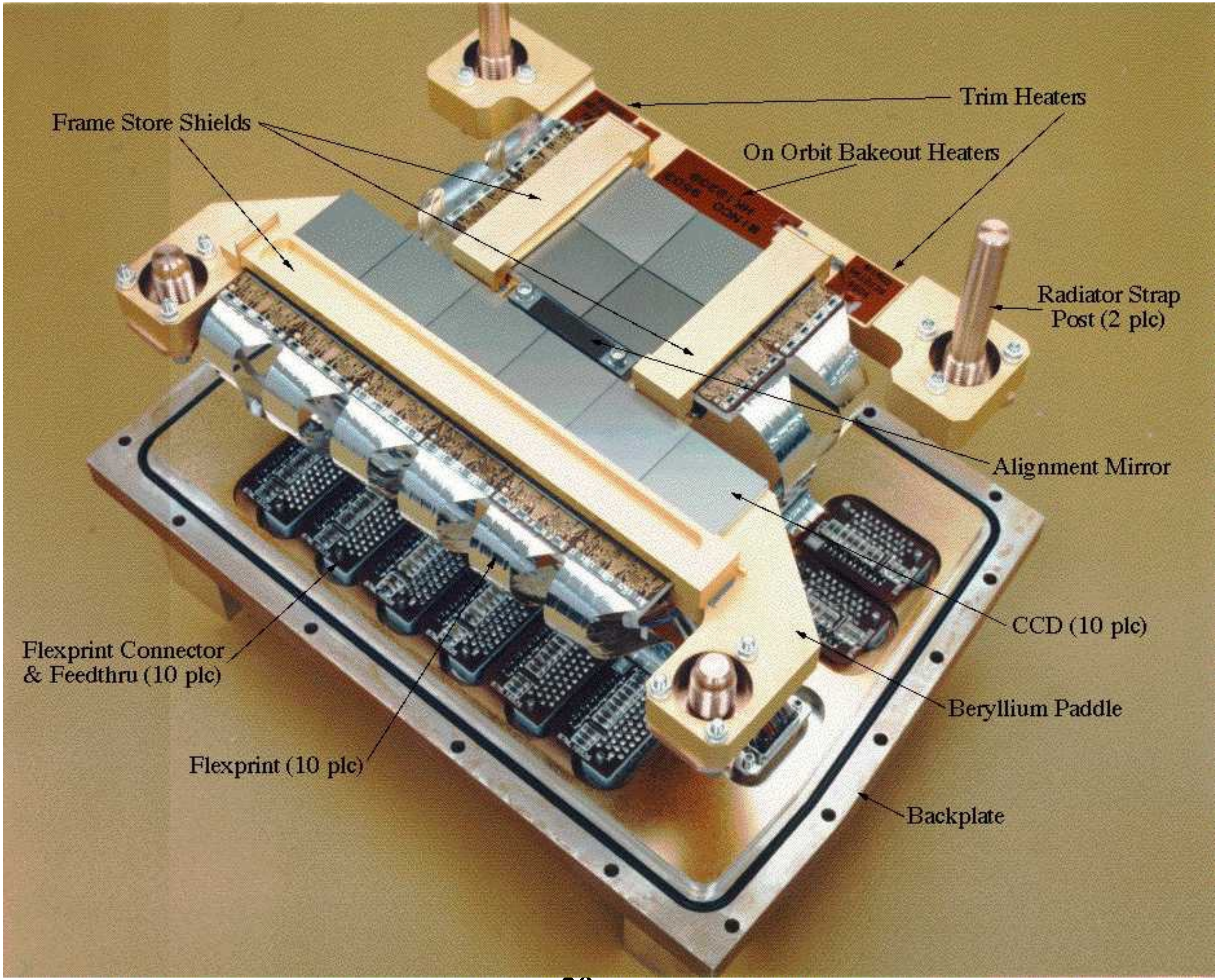


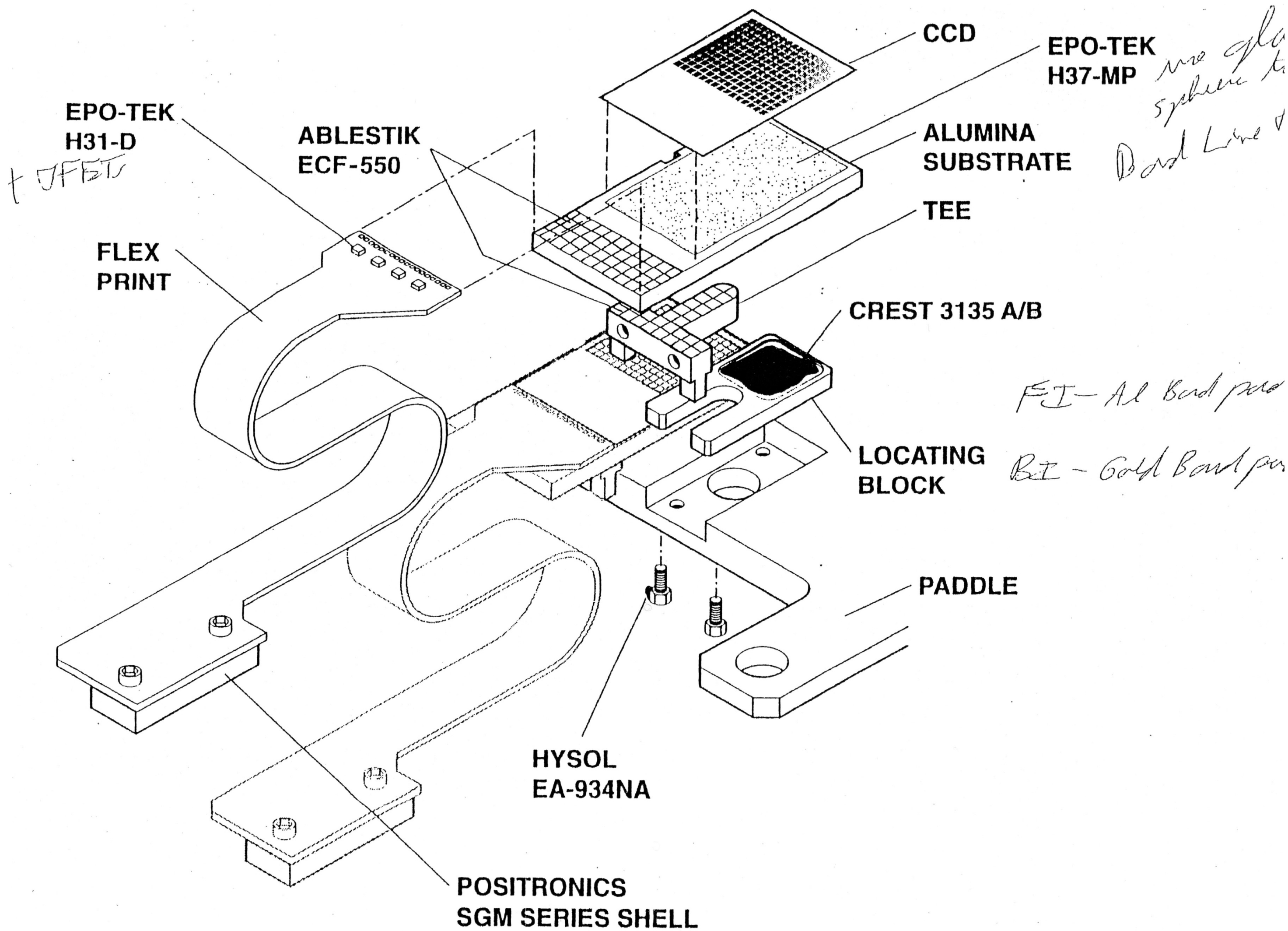
FIGURE 3. Front-End Processor Component Layout



ACIS Focal Plane



ACIS Paddle Design



HW Design and Lifetime Issues

- **DEA -** 10 video boards (VB), one VB hard-wired to one CCD, the loss of one VB would result in the loss of that CCD
- **DEA -** A/D converters *may* experience long-term degradation due to radiation exposure
- **DPA -** FEPs multiplexed to the CCDs, any FEP can process data from any CCDs
- **DPA -** FEP0 anomaly has been of no consequence since we started assigning FEP0 last
- **DPA -** both side A and side B of the DPA must be powered on to clock 6 CCDs
- **Radiators -** cooling capacity is consistent with pre-launch predictions, have difficulty maintaining -120 C at tail-Sun attitudes
- **CTI -** CTI of the FI CCDs slowly increasing, still many years away from the point at which the CCDs are no longer useful for scientific observations
- **Contamination -** contamination has increased so that 75% of the effective area at O VIII Ly-alpha (0.654 keV) has been lost

ACIS Mass

	Weight (lbs)
Detector Assembly	20.8
Venting Subsytem	8.7
Support Assembly	124*
Thermal Control and Isolation	5.4
Radiators	10.2
Sun & Telescope Shades	16.0
PSMC	32.7
PSMC Cables	9.1
SIM Mounted Cal Source	4.3
Total Weight	254 **

**** total weight from Observatory to SI ICD (CM07a), email from Bill Mayer**

***Email from Bill Mayer, all other weights from May 1997 Monthly Report**

Flight Operations

OPERATIONAL CONFIGURATIONS:

- Only three general ones thankfully, “Normal Science”,”Thermal Standby”, & “Radiation Shutdown” because there is so much margin in the spacecraft power budget

Mode	DPA A 1DP28AVO 1DPICACU	DPA B 1DP28BVO 1DPICBCU	DEA A 1DEA28AVO 1DEICACU	DA htr B 1DAHBVO 1DAHBCU	Total
Normal Science (6 CCDs)	40 W	35 W	57 W	5 W	137 W
Thermal Standby	40 W	35 W	26 W	5 W	106 W
Radiation Shutdown	12.5 W	8 W	26 W	5 W	51.5 W

- DPA A & B On; DEA A on, DEA B off, DA Htr side B On, this is “normal”
- DEA A power consumption will vary depending on the number of active CCDs
- DEA current monitor is noisy; must integrate to get an accurate reading
- Cold Radiator (1CR[AB]T) at -127.3 C, Warm Radiator (1WR[AB]T) at -82.0 C
- ACIS Ops web page **http://http://cxc.cfa.harvard.edu/acis/home.html** displays realtime data, average 10 samples, computes power

Flight Operations

Radiation Environment:

- The pre-launch concern was high energy protons (E>10 MeV), hence the heavy proton shield around ACIS
- The unfortunate discovery post-launch was that low-energy protons (~100 keV) reflected off of the mirror with a small but not negligible efficiency
- The solution was to translate the SIM to the HRC-S position for every perigee passage
- Low energy protons outside of the belts also produce damage
- EPHIN only measures protons from 5 MeV and up, the spectrum of the protons varies from one solar event to the next, sometimes the low and high energy protons both go up dramatically, sometimes only the low energy protons go up significantly
- Use ACE to monitor the 112-187 keV protons “on the way”, use GOES P2 channel (4-9 MeV) to better predict EPHIN P4 GM rates
- Use EPHIN P4GM, P41GM, and E1300 as SCS107 triggers; P41GM for hard proton events, P4GM for softer proton events, E1300 as a failsafe detector out of the belts
- HETG is assumed to provide a factor of 5 attenuation for 100 keV protons and the LETG a factor of 2

THE SIM MUST BE AT HRC-S (-99616) FOR EVERY PERIGEE PASSAGE !!!!!!

Flight Operations

Operational Issues and Concerns:

- Perigee passages - the SIM must be at HRC-S and the video boards powered down
- RADMON MUST be enabled if ACIS is in the focal plane
- **"Unsafe ACIS Response" -** procedures developed, SAP_UNSAFE_ACIS_PHASE1 and SOP_UNSAFE_ACIS_PHASE2.
- FP temperature regulation - it has become more difficult over the course of the mission to maintain -120 C on the FP. If the solar pitch angle is less than 120 and there is negligible Sun in the radiator FOV, there is no difficulty in maintaining -120 C
- Multiple Limit Sets - ODB, Greta, SOT M&TA, ACIS Ops, ODB
- PSMC gets warm for pitch angles between 45-60, (1PIN1AT, 1PDEA[AB]T)
- DPA and FP get warm for pitch angles larger than 120 (1DPAMZT)
- Large ACIS commands - ACIS PBs are much larger than most spacecraft commands. The loads cannot put another command directly after the ACIS PB command because the OBC will not complete processing the PB in time. The risk is that the load will hang.

Flight Operations

Operational Issues and Concerns (continued):

- ***THREATS to ACIS***
- SIM at the incorrect position
- Spacecraft attitude is incorrect so that the Sun is on the ACIS radiator or the HRMA
- Any future ACIS HW commanding. SW commanding should be innocuous.
- An ACIS bakeout.
- Contamination damages the instrument, perhaps the OBF
- PSMC gets warm enough that a component fails

FEP0 Anomaly

What is it ?

FEP0 reports a large number of bias parity errors for half a CCD, preventing events from being reported from that CCD. Possible HW failure on the FEP board in which there is crosstalk between two signal lines.

When did it happen ?

Early in the mission, Fall 1999. It has not occurred since we starting assigning FEP0 last

Will it happen again ?

Possibly, but FEP0 must be on. FEP0 is the least used FEP, so this appears unlikely.

What is the first response ?

Most likely we will be notified by CXCDS Ops that data from the CCD attached to FEP0 looks anomalous. We need to process the dump data and get access to the CXC products, send an email to the ACIS team (including Peter, Bob, Mark, Bev), and convene a telecon at the next reasonable moment. We should examine the load to see when the next observation that uses FEP0 is scheduled.

Threshold Crossing Plane Latchup - Trickle Bias Anomaly

What is it ?

The BEP starts the acquisition of event data before the bias maps have been telemetered fully and starts interleaving event data with bias data. The two telemetery processes access the same memory chip and can cause it latch-up depending on the timing of the requests. A T-plane latch-up means the same pixels get reported as events frame after frame regardless of the contents of the pixel.

When did it happen ?

From the beginning of the mission through 2013. There were 14 instances of the trickle-bias anomaly and four resulted in T-plane latch-ups.

Will it happen again ?

The patch *buscrash2* is intended to prevent the trickle bias anomaly. Previous patches were not successful in preventing the anomaly but did reduce it. No occurrences since 2013.

What is the first response ?

Most likely we will be notified by CXCDS Ops that data from one of the CCDs looks anomalous. We need to process the dump data and get access to the CXC products, send an email to the ACIS team (including Peter, Bob, Mark, Bev), and convene a telecon at the next reasonable moment. We should examine data from the next observation because power-cycling the FEPs should clear the condition. But if the next observation uses the same configuration, the FEPs will not be power cycled and the anomaly will persist.

DPA A or DPA B Anomalous Shutdown

What is it ?

The DPA A or DPA B shutdown anomalously presumably to a spurious command. See Flight Notes 394 and 417.

When did it happen ?

The DPA A has shut down 3 times over the mission and the DPA B has shutdown once. Last DPA A shutdown was in 2015.

Will it happen again ?

It appears likely that the anomaly will occur again if the mission continues.

What is the first response ?

Our realtime web pages will alert us and the Lead System Engineer will call us. We need to process the dump data and make sure that there is nothing anomalous in the data *BEFORE* the shutdown. We want to know if a new occurrence looks just like the previous occurrences. If yes, it should appear as if in one frame the DPA A turned off. We need to process the dump data, send an email to the ACIS team (including Peter, Bob, Mark, Bev), and convene a telecon at the next reasonable moment. DPA A shutdowns require reloading the patches, restarting DEA HKP, and resetting the FP temperature. DPA B shutdowns just require that the DPA B be powered back on.

DEA A Anomalous Shutdown

What is it ?

The DEA A shut down anomalously presumably to a spurious command. See Dick's and Gregg's flight note on the event.

When did it happen ?

The DEA A has shut down only once in the mission in 2005.

Will it happen again ?

It appears it could happen again, but one occurrence in 16 years provides little guidance.

What is the first response ?

Our realtime web pages will alert us and the Lead System Engineer will call us. We need to process the dump data and make sure that there is nothing anomalous in the data *BEFORE* the shutdown. We want to know if a new occurrence looks just like the previous occurrences. If yes, it should appear as if in one frame the DEA A turned off. We need to process the dump data, send an email to the ACIS team (including Peter, Bob, Mark, Bev), and convene a telecon at the next reasonable moment. A DEA A recovery requires that the BEP be warm booted after the DEA A is back on (see SOP and Flight Note for details).

FEP Reset During a Science Observation

What is it ?

A single FEP or the three FEPs on side B can reset during an observation, resulting in loss of science data from the affected FEPs for the rest of the science run.

When did it happen ?

Several times over the mission, last occurrence was 2013. See various Flight Notes on this issue.

Will it happen again ?

It appears likely it could happen again. Side B of the DPA seems particularly susceptible to power transients.

What is the first response ?

Most likely we will be notified by CXCDS Ops that data from one or more of the CCDs stopped during an observation. We need to process the dump data and get access to the CXC products, send an email to the ACIS team (including Peter, Bob, Mark, Bev), and convene a telecon at the next reasonable moment. We should examine data from the next observation because power-cycling the FEPs should clear the condition. But if the next observation uses the same configuration, the FEPs will not be power cycled and the anomaly will persist.

DEA Sequencer Reset During a Science Observation

What is it ?

The DEA sequencer crashes, resulting in loss of science data from all video boards for the rest of the science run.

When did it happen ?

Several times over the mission, last occurrence was 2013.

Will it happen again ?

It appears likely it could happen again.

What is the first response ?

Most likely we will be notified by CXCDS Ops that data ceased prematurely for an observation. We need to process the dump data and get access to the CXC products, send an email to the ACIS team (including Peter, Bob, Mark, Bev), and convene a telecon at the next reasonable moment. We should examine data from the next observation because the setup for the next observation should clear the problem.

Hi-Lo Pixel Anomaly

What is it ?

Event data stops being reported for one CCD/FEP combination and the delta overclock values are peculiar, large and negative for the first three output nodes and large and positive for the fourth output node.

When did it happen ?

Twice once in 2011 and once in 2013.

Will it happen again ?

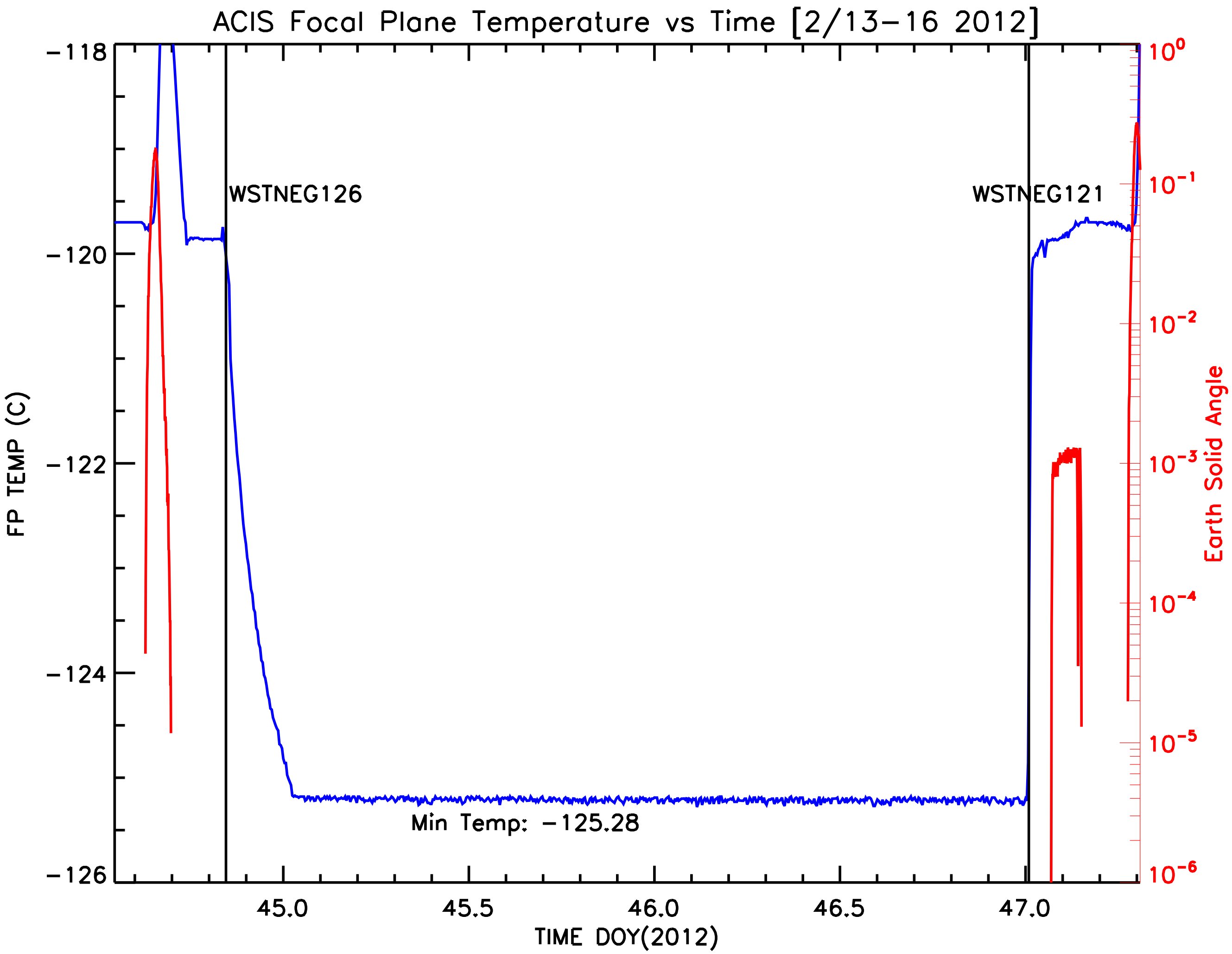
It appears likely it could happen again.

What is the first response ?

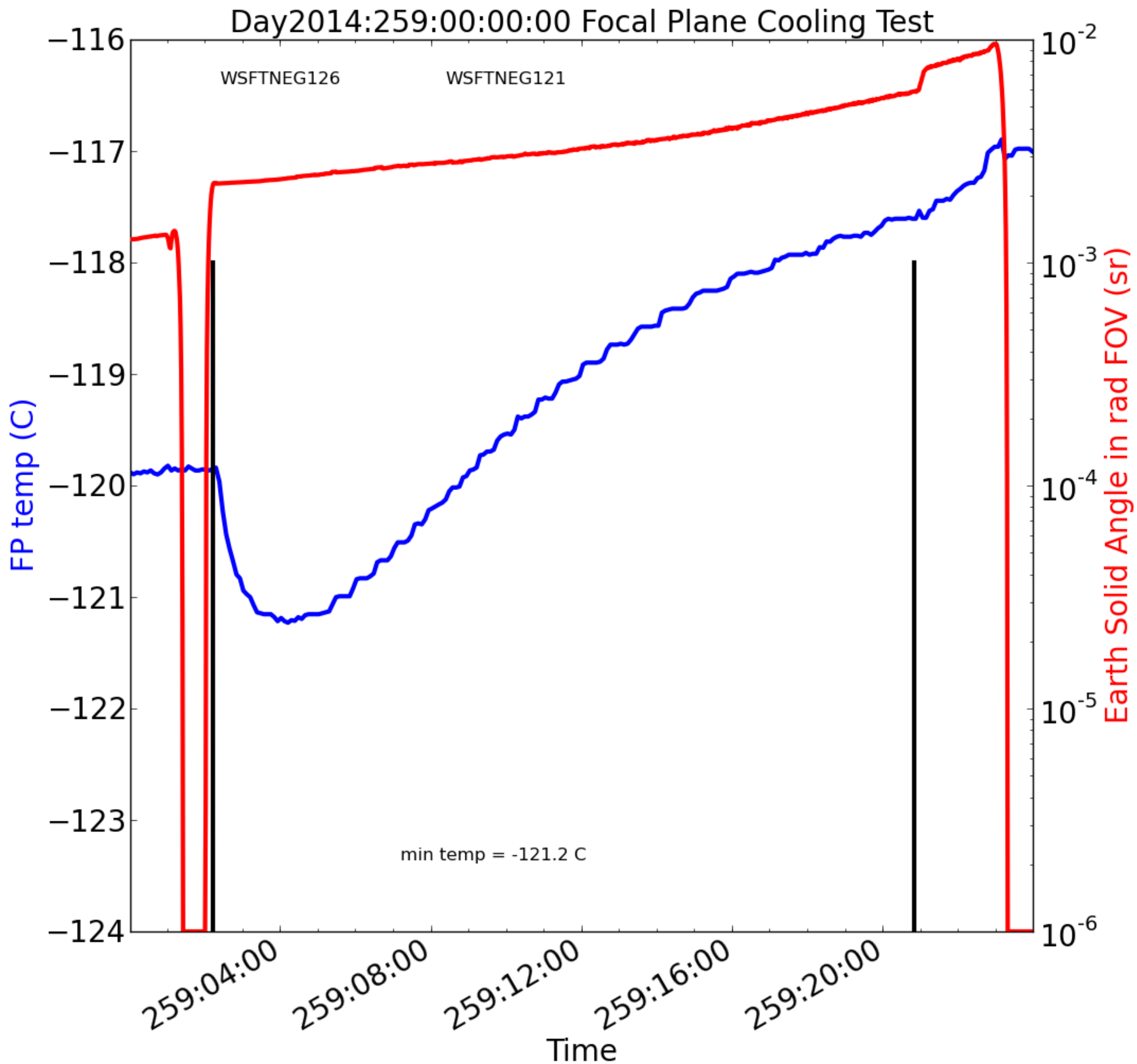
Most likely we will be notified by CXCDS Ops that data ceased prematurely for a single CCD for an observation. But there is a chance we can catch this anomaly in a realtime contact during a long observation. If yes, we have an SOP (SOP_ACIS_DEA_FEP_DIAGNOSTICS) written to intervene if the observation with the anomaly is still in progress to dump diagnostic data. If not, we need to process the dump data and get access to the CXC products, send an email to the ACIS team (including Peter, Bob, Mark, Bev), and convene a telecon at the next reasonable moment. We should examine data from the next observation because the setup for the next observation should clear the problem.

ACIS FP Cooling Tests

http://cxc.cfa.harvard.edu/acis/FP_cooling/index.html



ACIS FP Cooling Tests



Initial Damage of the ACIS CCDs

- ACIS-S was at the "launch-lock" position, launch on DOY 204 (1999)
- First measurements of internal Fe-55 source were nominal on DOY 210
- ACIS Door was opened on DOY 220 and Aft Contamination Cover of the HRMA was opened on DOY 223
- Measurements of calibration sources on Forward Contamination Cover (FCC) were nominal on DOY 224 (see Elsner et al. SPIE 2000)
- FCC opened late on DOY 224, first light with ACIS, first unprotected perigee passage on DOY 225
- ACIS-S at focus for 5 perigee transits, ACIS-I for 3 perigee transits, and ACIS-S/HETG for 2 perigee transits
- Large increase in CTI discovered on DOY 250, DOY 257 was the last ``unprotected" perigee transit and DOY 260 was the last ACIS-S/HETG perigee transit

Radiation Damage of the ACIS CCDs

- **The CTI increase was caused by low-energy (~100 keV) protons, which scatter off of the mirror surfaces to the focal plane.**
- **All 8 FI CCDs exhibit a large increase in CTI, damage is restricted to the imaging region, framestore regions are unaffected.**
- **Neither of the BI CCDs shows any damage.**
- **No increase in the dark current of the FI CCDs.**
- **Irradiation of flight-like CCDs with 100-150 keV protons produces similar damage.**
- **Prigozihn *et al.* (2000) identify 4 types of traps, two with timescales of tens to hundreds of μs, one with hundreds of ms, and one on the order of several seconds**
- **Kolodziecjzak et al. (SPIE 2000) simulated the scattering of protons off of the HRMA and transmission to the focal plane, they conclude that it is plausible but their model underpredicts the damage by a factor of 3-4 and preliminary ground measurements indicate the scattering efficiency is not high enough**

Operational Response

- ACIS is always moved out of the focus of the HRMA before radiation belt transit.
- A 10 ks "pad" has been added on either side of the radiation belts.
- Data from other satellites with sensitivity to low-energy protons have been incorporated into the *Chandra* alert system.
- On-board thresholds for safing have been adjusted.

Mitigation Techniques

- Operate the CCDs as cold as possible, currently -120 C.
- Develop a phenomenological correction for the effects of CTI, improve the quality of the data
- perhaps use new modes in the future which will report additional information for each event which could lead to a better correction for CTI

ACIS Contamination: Brief Description of the Problem

Problem: **A layer of contamination is building up on the ACIS Optical Blocking Filter (OBF).**

Impact: **The contamination layer reduces the transmission of X-ray photons through the OBF, thereby reducing the number of photons which reach the CCDs. This decreases the effective area of the *High-Resolution Mirror Assembly* (HRMA) and ACIS system. The ``effective area" is defined as the combination of the collecting area of the HRMA, the transmission of the OBF, and the detection efficiency of the CCDs. The ``detection efficiency" is defined as the probabilty of detecting a photon which strikes the detector.**

This effect is energy-dependent, affecting low energies most. The decreased sensitivity results in:

- → **longer observing times to achieve the same science objective**
- → **loss of some science programs because they are no longer feasible**

Contamination, Bakeouts & CTI Increase

- Contamination was expected on ACIS during the mission since ACIS contains the coldest surfaces internal to the spacecraft
- The pre-launch plan was to bake ACIS out at regular intervals to minimize the buildup of contamination
- There have been two ACIS bakeouts to room temperature in the mission, both early in 1999. The first bakeout was part of the ACIS door opening procedure. The CCDs were functioning nominnally before and after this bakeout.
- The CCDs suffered radiation damage from low-energy protons (~100 keV) in August and September 1999. Further damage has been minimized by moving ACIS out of the focus of the HRMA during radiation belt passages.
- The second room temperature bakeout was an attempt to ``anneal" the CCDs (to reverse some of the effects of the radiation damage). Unfortunately, the CCD performance got worse after the second room temperature bakeout (CTI increased by 30%).
- This leads to the expectation of increased CTI for another bakeout.

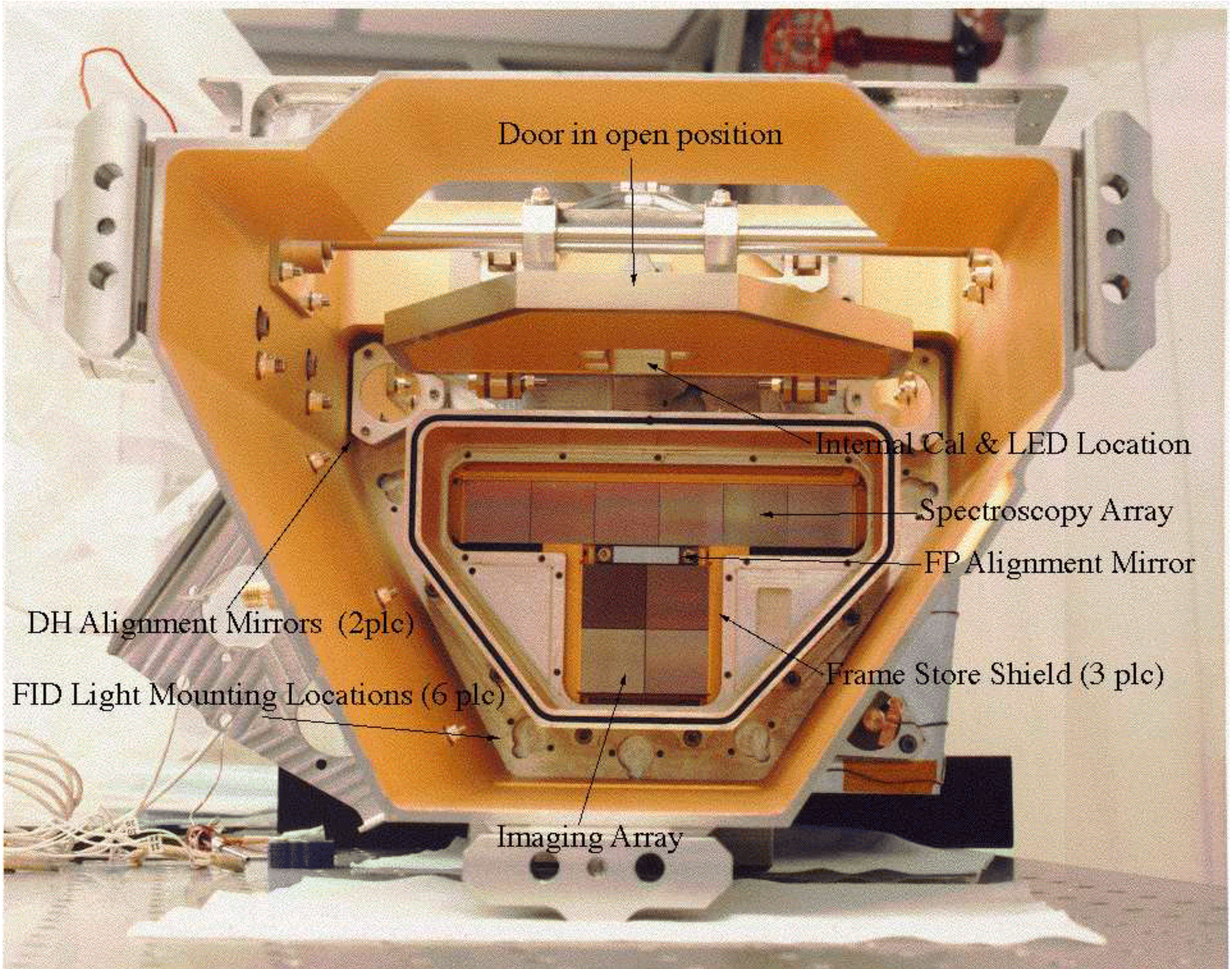
Risks Associated with Bakeout

Definition: **Risk to the spacecraft or instrument health & safety, and/or to the science mission.**

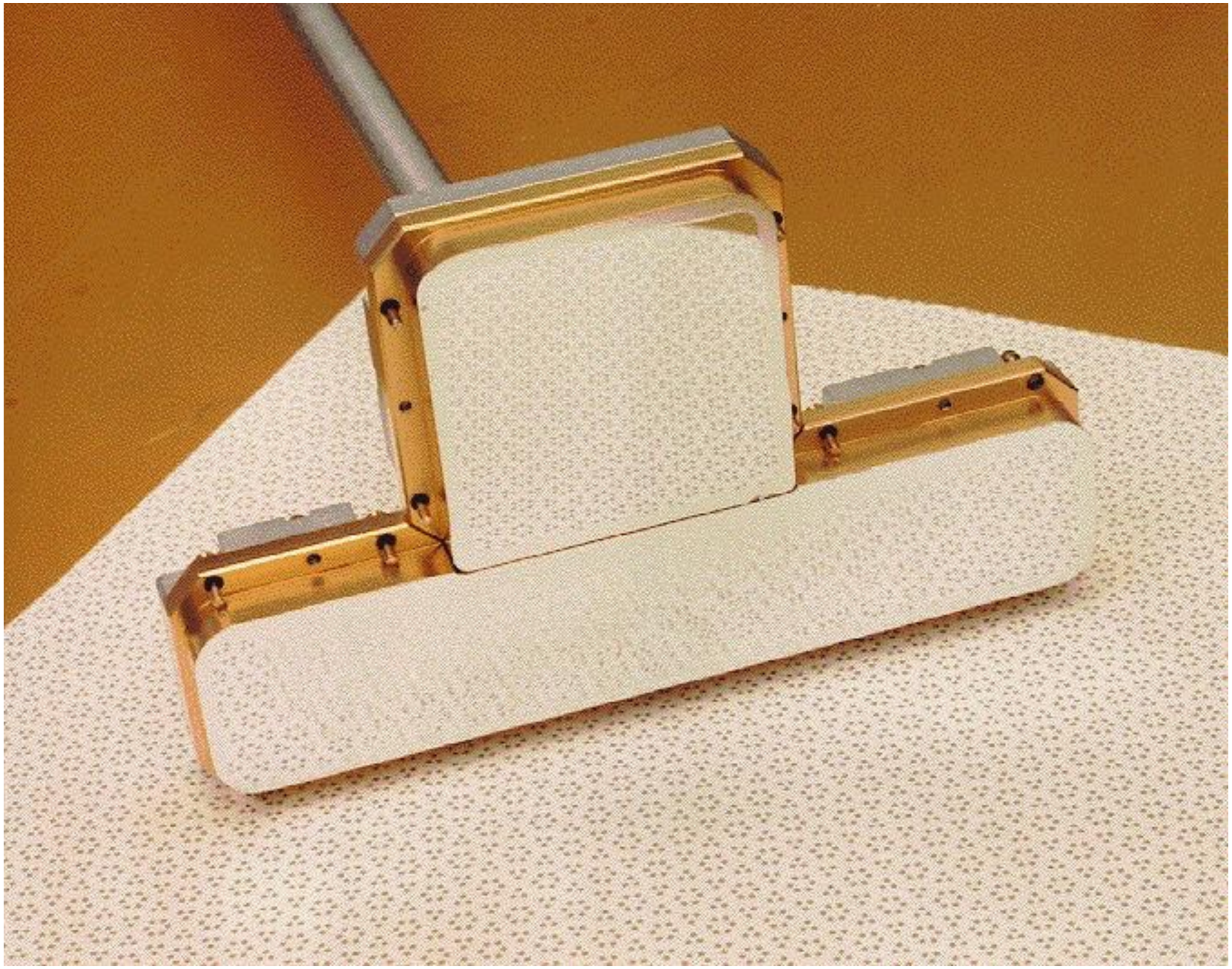
1) **Thermal cycling results in a HW failure in the ACIS instrument**
2) **Damage to the OBF**
3) **CTI increases by a larger than anticipated amount**
4) **Unexpected change in contamination**
   - 4a) **contamination increases in thickness**
   - 4b) **contamination returns quickly**
   - 4c) **contamination migrates to another spacecraft system**
5) **Thermal cycling has a negative impact on the spacecraft**

Risk Assessment

RISK	MITIGATION	IMPACT	PROBABILITY
1. HW failure due to thermal cycling	Assessment by ACIS engineering team, HW design, previous bakeouts	Moderate Possible degradation	Very low
2. OBF Damage	Ground tests at NGST on spare flight OBFs	High Potential loss of instrument	Low
3. Larger than anticipated CTI increase	Ground irradiation tests on spare flight CCDs	Low Loss of science	Very low
4. Undesirable change in contamination	Simulations of bakeout, materials testing	Moderate Loss of science	Low
5. Thermal cycle has adverse effect on spacecraft	Assessment by Chandra FOT and NGST	Low Possible misalignment	Very low


Door in open position
Internal Cal & LED Location
Spectroscopy Array
FP Alignment Mirror
DH Alignment Mirrors (2plc)
Frame Store Shield (3 plc)
FID Light Mounting Locations (6 plc)
Imaging Array

ACIS Optical Blocking Filter



ACIS-I OBF

Al/Polyimide/Al

1200A/2000A/400A

ACIS-S OBF

Al/Polyimide/Al

1000A/2000A/300A

Thermal Models of the ACIS Instrument

Purpose: In order to model and understand the bakeout, one must know the temperatures of all the surfaces the contaminant might encounter.

Modeling – provided by Neil Tice at LMA, ACIS thermal engineer pre- and post-launch

Collimator – primary surface which the contaminant will interact with on its way out of the instrument during the bakeout

Detector Housing – upper portion probably contains the majority of the contaminant by mass and the OBFs are installed in the DH

OBFs – significant temperature gradient across the filters

In order to model the bakeout, the temperatures of the relevant surfaces in ACIS must be known for:

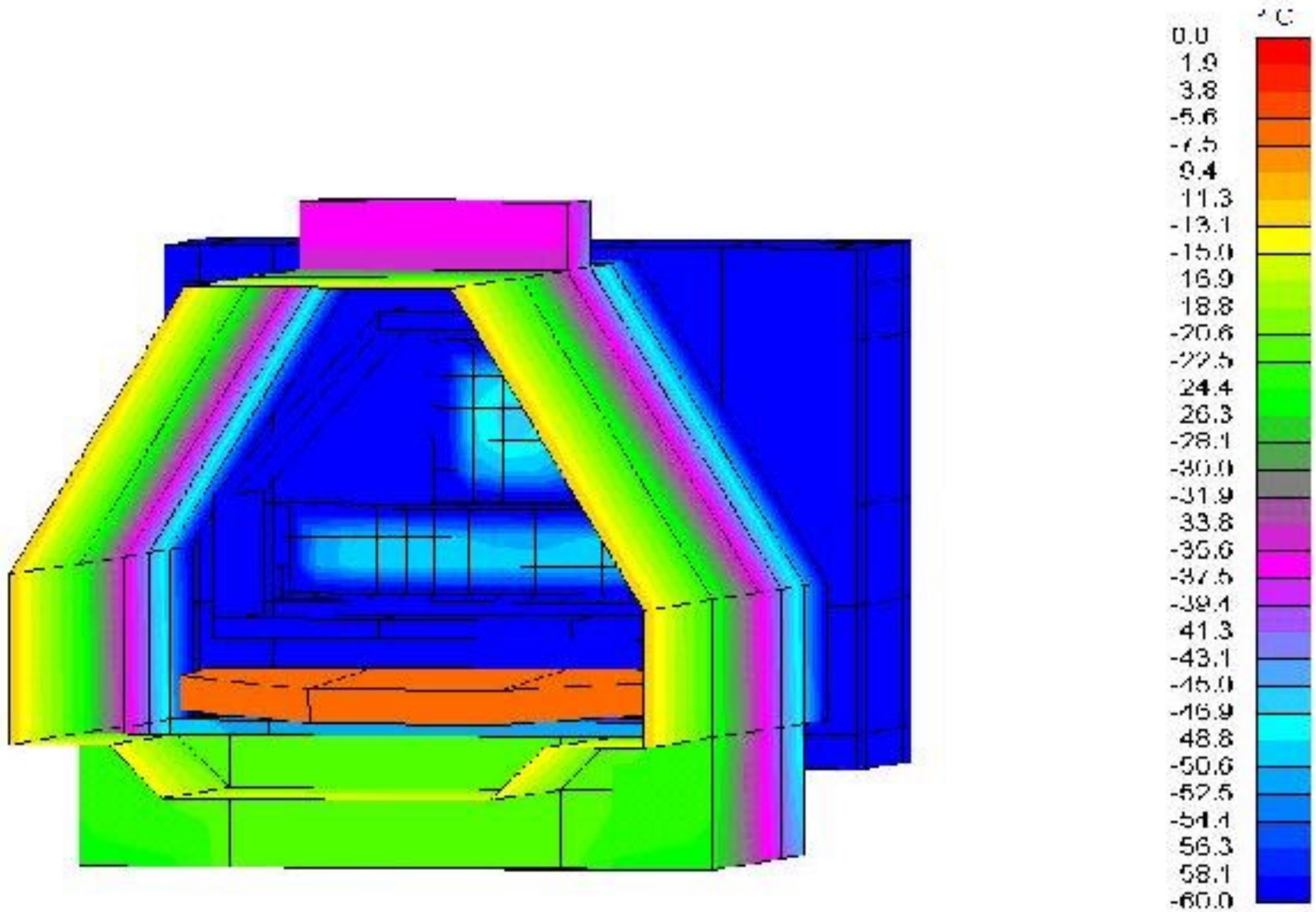
1) Normal operations, FP= -120 C, DH=-60 C

2) Bakeout conditions, FP= +20 C, DH=+20 C

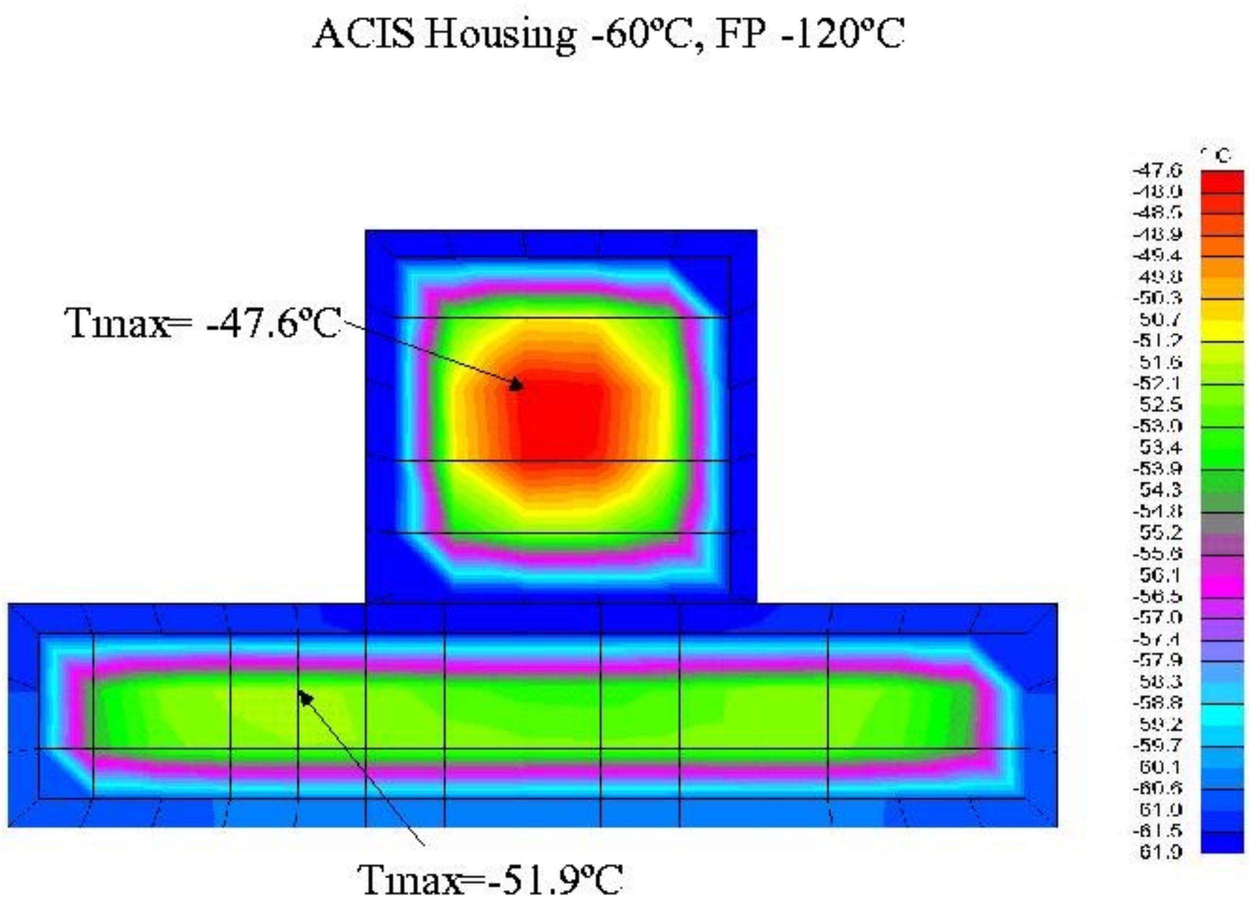
ACIS Temperatures During Nominal Operation
Focal Plane is a –120°C

Tice

(LMA)



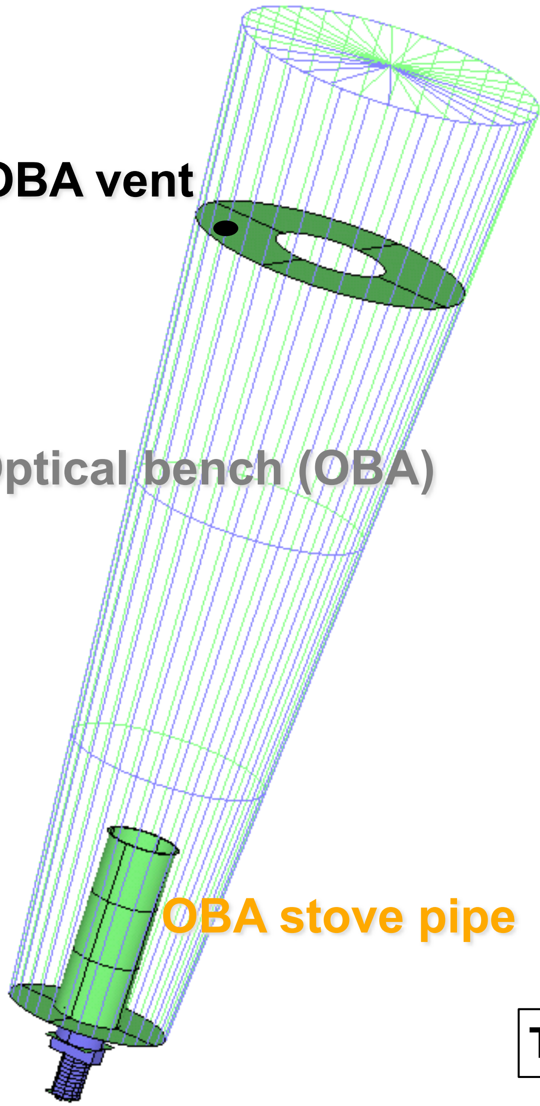
ACIS Filter Temperatures for Standard Conditions

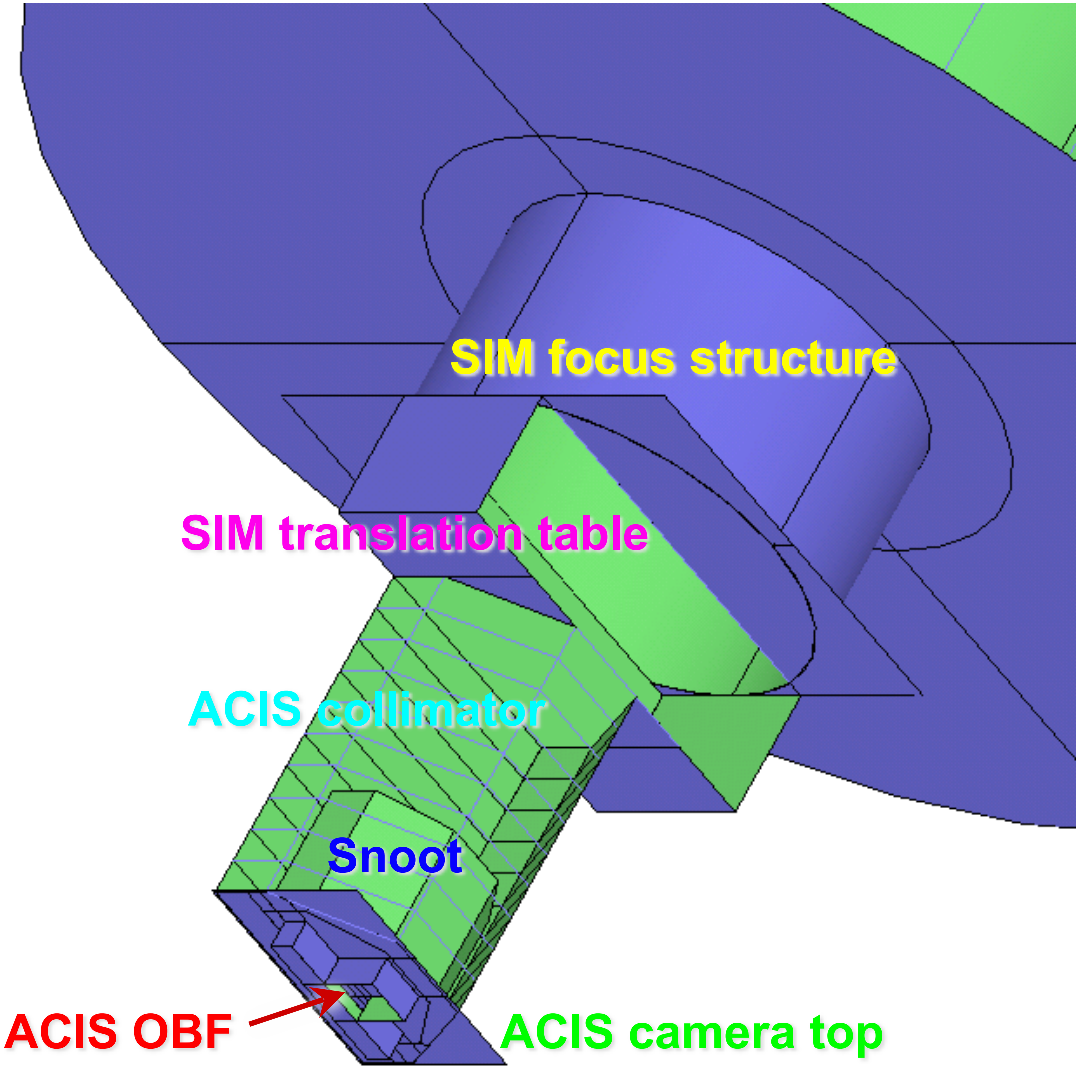


Tice

(LMA)

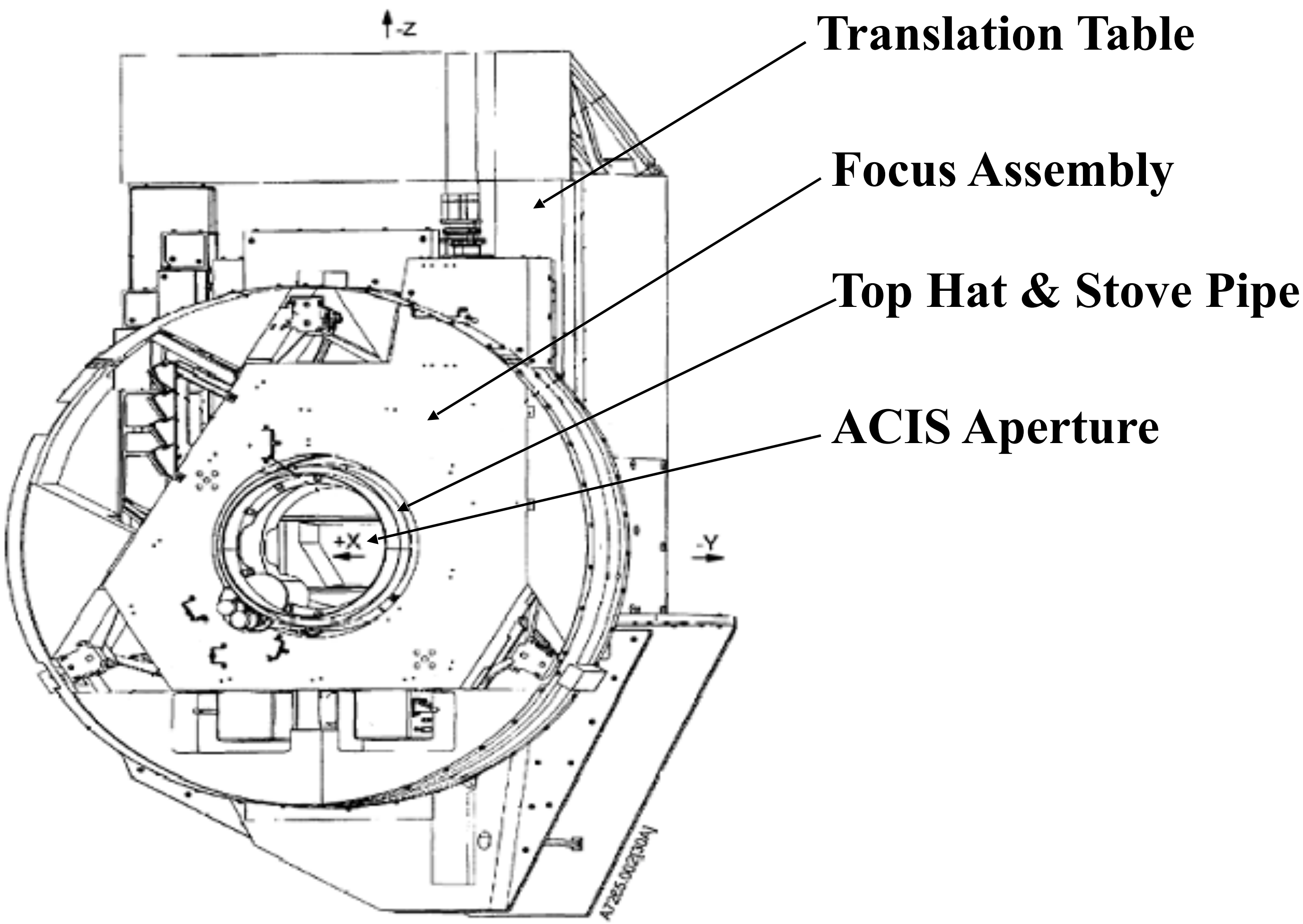
Geometric model



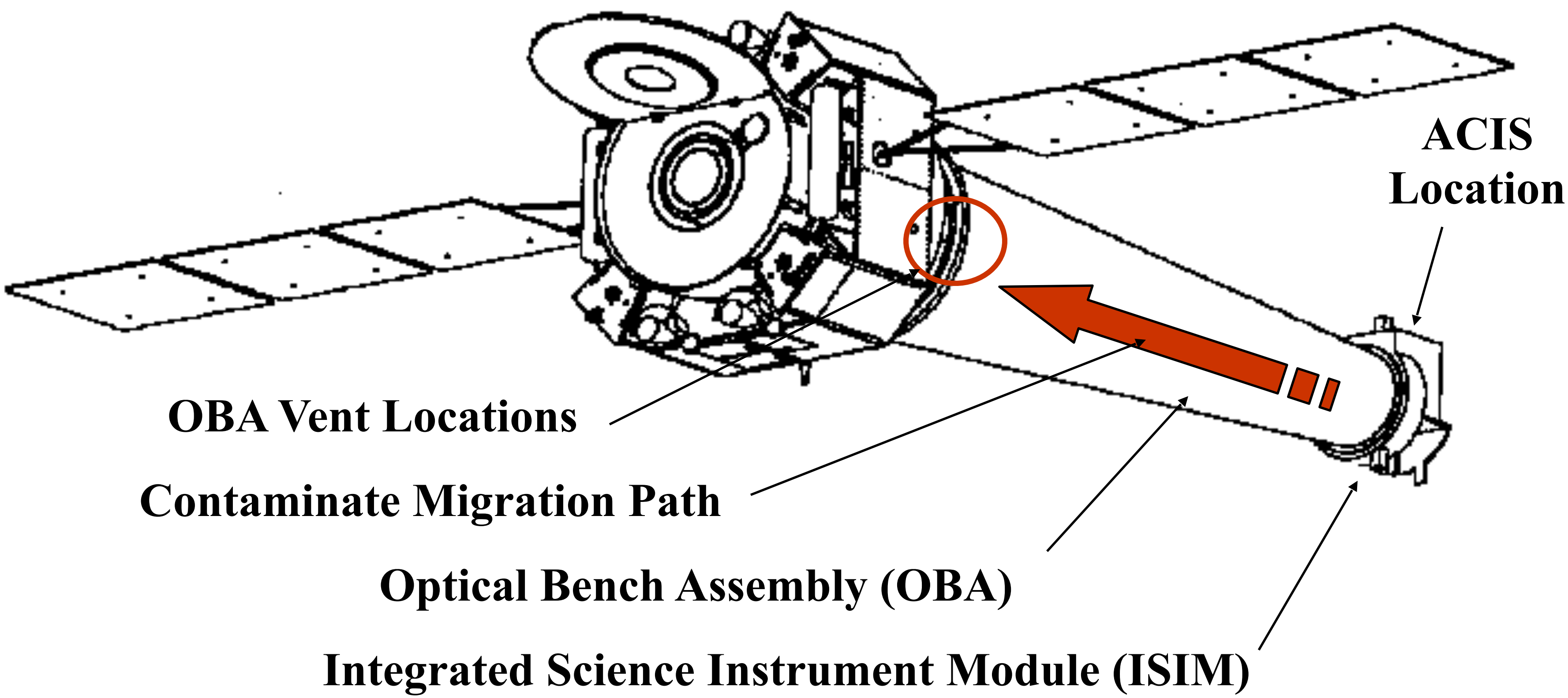


TRASYS model by NGST/ H. Tran et al.

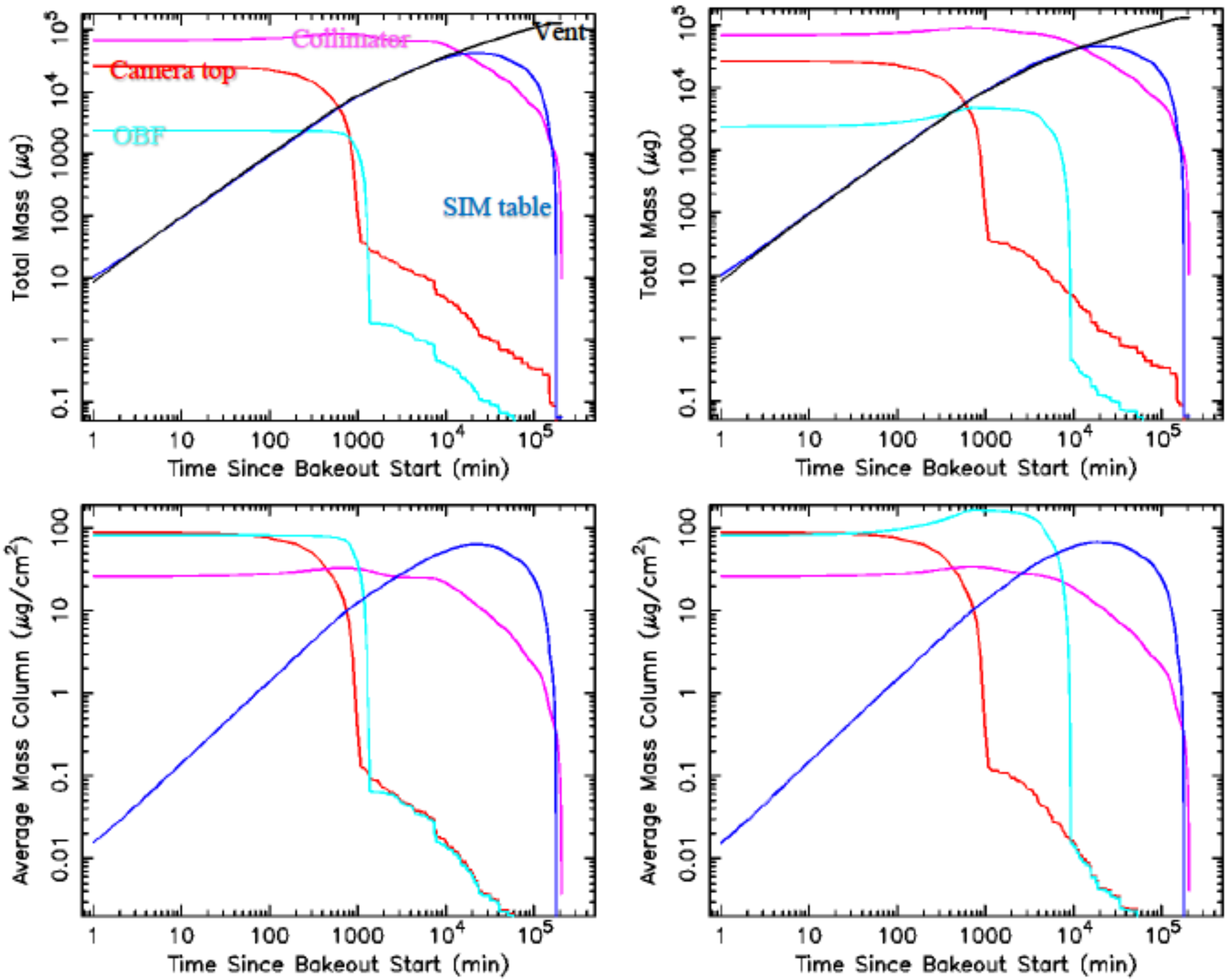
Integrated Science Instrument Module



Contaminant Path of Travel



FP=+25.0 C FP=-60.0 C



Bakeout

Simulations

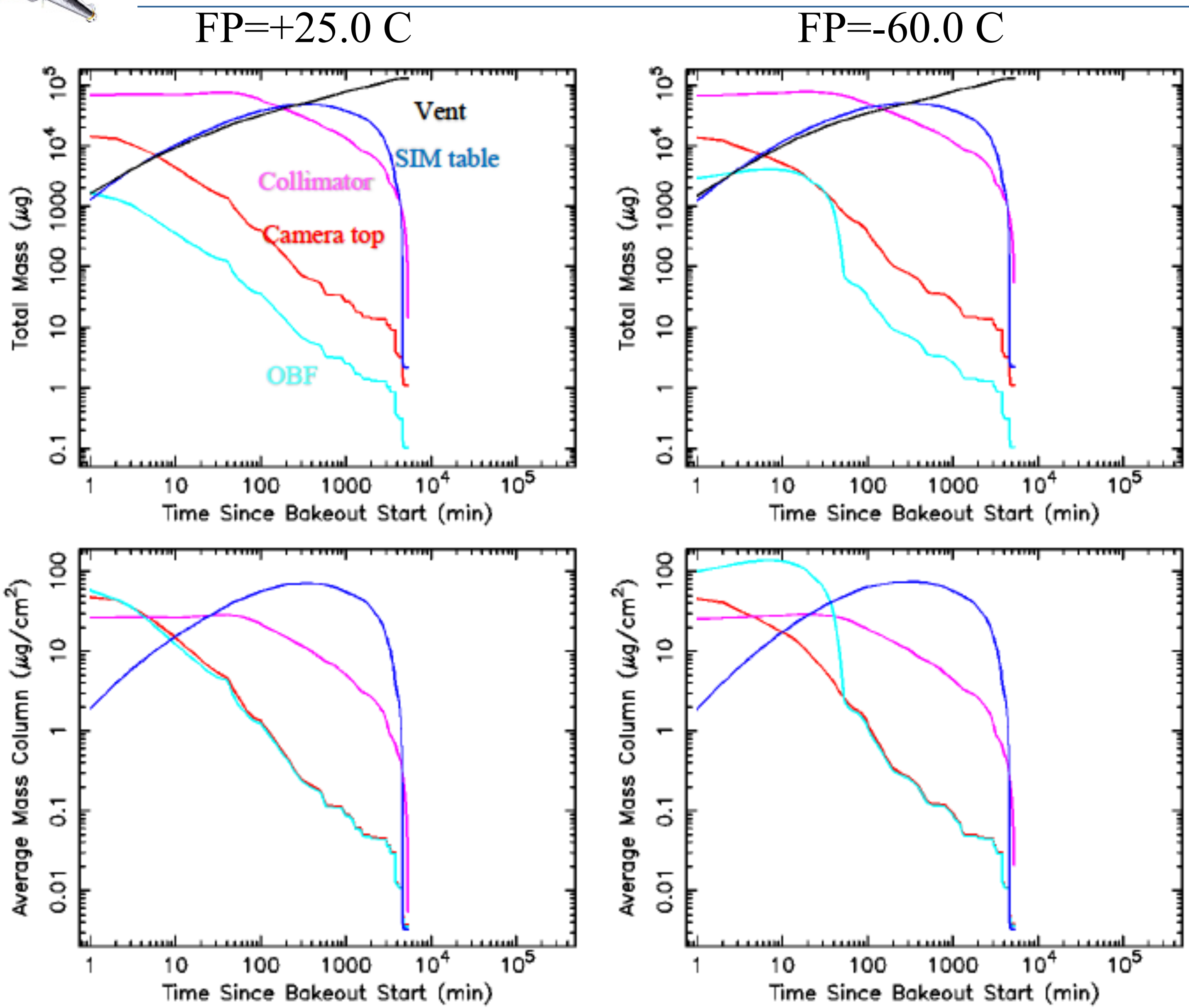
O'Dell & Swartz 2015 (MSFC)

Dioctyl Phthalate (DOP)

ACIS OBF
Camera top
ACIS collimator
SIM trans table
OBA vent

2×10^5 min = 139 days

Chandra X-Ray Observatory



Bakeout

Simulations

O'Dell & Swartz 2015 (MSFC)

Octadecane

ACIS OBF
Camera top
ACIS collimator
SIM trans table
OBA vent

6×10^3 min = 4 days