Modeling contamination migration on the Chandra X-ray Observatory — III

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UV, X-Ray, and Gamma-Ray Space Instrumentation for Astronomy XIX
2015 August 9-10, San Diego, CA USA
Outline

- Introduction
- Molecular contamination on ACIS filters
- Thermal model for ACIS cavity
- Molecular transport simulations
- Summary
Chandra’s Advanced CCD Imaging Spectrometer (ACIS)

- ACIS cavity
  - Collimator
  - Snoot & door
  - Camera top & filters (OBF)

- ACIS operating temperatures
  - Focal plane $T_{FP} = -120^\circ C$
  - Camera housing $T_{DH} = -60^\circ C$
    - $\approx 8^\circ C$ colder with heaters off
  - Optical blocking filters $T_{OBF}$
    - $\approx T_{DH} \approx -60^\circ C$ near OBF edge
    - 5–20°C warmer near center depending on emissivity $\varepsilon_{OBF}$

- Contamination on cold OBFs
  - Mass column $\approx 200 \mu g \text{ cm}^{-2}$.
    - $\leq 1 \text{ g}$ in entire Chandra optical cavity (calculated)
    - $\approx 30 \times$ pre-flight estimates
  - Thicker near OBF edge
Contamination-migration simulations for Chandra

2004 (I)
- Low-resolution geometrical model for ACIS cavity
- Supported bake-out decision in 2004

2013 (II)
- High-resolution geometrical model for ACIS cavity
- Higher emissivity for contaminated surfaces

2015 (III)
- Same model as 2013
- Will support bake-out decision in 2016
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Evolution of mass column, its rate, and composition

Accumulation of contaminants

- LETG/ACIS-S spectra
  - Atomic (C,O,F) edge depths
  - Thickest near OBF edges

Rate fell until about 2009 then started rising.

Composition changes indicate multiple species.
Temperature dependence of mass vaporization rate

Mass vaporization rates of some organic compounds

- tetradecane
- pentadecane
- hexadecane
- heptadecane
- octadecane
- nonadecane
- eicosane
- henicosane
- docosane
- tricosane
- tetracosane
- DOP

Vaporization rate $D_{\text{v}}$ [$\mu g \text{ cm}^{-2} \text{ s}^{-1}$]

Temperature $T$ [°C]
Most systems are warming.
- Continuing degradation of external insulation (MLI)
- Strive to keep ACIS focal plane cold to preserve performance.
  - Carefully plan observations.
  - Disabled some heaters.
    - ACIS detector-housing heater (2008 April)
    - A SIM focus-assembly heater (2009 August)
- Optical bench has warmed rapidly since about 2010.
  - New contamination source?
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ACIS geometric model (interior view)

- Interior view of ACIS cavity
  - Snoot & door inside collimator
  - Camera top with OBFSs

- High-resolution model maps temperature gradients
  - OBF: 121 I & 203 S nodes
  - Collimator: 12 axial zones

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ACIS temperature distribution (operational conditions)

- DH heater OFF, \( T_{FP} = -120^\circ C \)
- \( T_{DH} = -60^\circ C, T_{FP} = -120^\circ C \)

\( \varepsilon_{OBF} = 0.40 \)

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Paper 6
Slide 11
ACIS temperature distribution (operational conditions)

- DH heater OFF, $T_{FP} = -120^\circ C$
- $T_{DH} = -60^\circ C$, $T_{FP} = -120^\circ C$

$\varepsilon_{OBF} = 0.40$

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ACIS temperature distribution (bake-out conditions)

- $T_{DH} = +25^\circ C$, $T_{FP} = -60^\circ C$
- $T_{DH} = +25^\circ C$, $T_{FP} = +25^\circ C$

$\varepsilon_{OBF} = 0.40$
ACIS temperature distribution (bake-out conditions)

- $T_{DH} = +25^\circ C, T_{FP} = -60^\circ C$
- $T_{DH} = +25^\circ C, T_{FP} = +25^\circ C$

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Molecular flux equations and geometric view factors

- Net mass flux onto node j
  \[
  \frac{d\mu_j}{dt} = -\dot{\mu}_v(T_j)\Theta(\mu_j) + \sum_k \dot{\mu}_v(T_k)\Theta(\mu_k) f_{jk} \frac{A_k}{A_j}
  \]

- Mass vaporization flux
  - Related to vapor pressure
    \[
    \dot{\mu}_v(T) = \frac{P_v(T)}{\sqrt{2\pi RT/M}}
    \]

- Clausius–Clapeyron relation
  - Temperature dependence
  - Vaporization enthalpy \( \Delta_v H \)

  \[
  P_v(T) = P_v(T_o) \exp\left[\frac{-\Delta_v H}{R} \left(\frac{1}{T} - \frac{1}{T_o}\right)\right]
  \]

  \[
  \dot{\mu}_v(T) = \dot{\mu}_v(T_o) \sqrt{\frac{T_o}{T}} \exp\left[\frac{-\Delta_v H}{R} \left(\frac{1}{T} - \frac{1}{T_o}\right)\right]
  \]

- Geometric view factors
  \[
  f_{jk} = n_k \cdot \Omega_{jk} / \pi
  \]

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Simulations of contaminant accumulation onto ACIS OBFS

- Lower volatility contaminant
  - Deposition dominates.
    - Accumulates most at center.

- Higher volatility contaminant
  - Vaporization is significant.
    - Accumulates most at edges.

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Accumulation simulation: two components

- **Low-volatility component**
  - Source rate drops exponentially due to depletion.
    - 3.7-year timescale

- **Medium-volatility component**
  - Source rate rises with increasing optical-bench $T_{OB}$.
    - $\propto \exp[-\text{constant}/T_{OB}]$
    - Rises until source depletion occurs.
Vaporization rate: Dependence upon phase state

Mass vaporization rates of a solid and of a liquid

- Octadecane
- DOP

Vaporization rate $D_{v,p}$ [μg cm$^{-2}$ s$^{-1}$]

Temperature $T$ [°C]

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Bake-out simulation: Octadecane mass

- **Warm focal plane**
  - \( T_{DH} = +25^\circ C \)
  - \( T_{FP} = +25^\circ C \)

- **Cool focal plane**
  - \( T_{DH} = +25^\circ C \)
  - \( T_{FP} = -60^\circ C \)

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Bake-out simulation: Octadecane column

- **Warm focal plane**
  - $T_{DH} = +25^\circ C$
  - $T_{FP} = +25^\circ C$

- **Cool focal plane**
  - $T_{DH} = +25^\circ C$
  - $T_{FP} = -60^\circ C$

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Warm focal plane
- $T_{DH} = +25^\circ C$
- $T_{FP} = +25^\circ C$

Cool focal plane
- $T_{DH} = +25^\circ C$
- $T_{FP} = -60^\circ C$
Bake-out simulation: Dioctyl phthalate column

- **Warm focal plane**
  - $T_{DH} = +25^\circ C$
  - $T_{FP} = +25^\circ C$

- **Cool focal plane**
  - $T_{DH} = +25^\circ C$
  - $T_{FP} = -60^\circ C$

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Summary

- Contamination-migration simulation provides a useful tool.
  - Utility for absolute predictions is still limited.
    - Absolute predictions require knowledge of contaminant’s volatility.
    - Uncertainty in temperatures propagates exponentially to rate error.
  - Model may require additional physics.
    - Treatment of multiple molecular species
    - Dependence of thermal emissivity upon contaminant mass column
      - Affects temperature distribution and thus mass vaporization rate
    - Surface redistribution, especially for a liquid contaminant
- Will use model to provide input for a bake-out decision.
  - Constrain properties of molecular contaminant(s).
  - Simulate contamination migration under potential scenarios.
    - Turning housing heaters back ON
    - Various bake-out conditions for ACIS